The effects of nutrient treatments of potato plants on the performance of their progeny.

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of the Bath University of Technology

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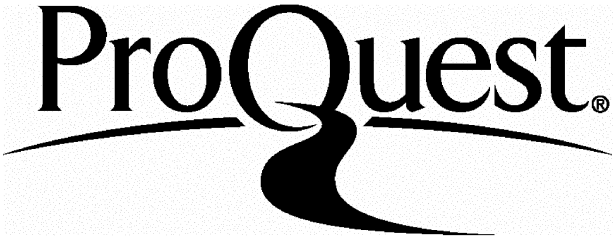

SUMMARY

Previous seed crop nutrition was shown to affect

1 - The eye number/tuber weight relationship of the seed tuber

2 - The time before sprouts appeared on the seed tuber

3 - The proportion of eyes which produced visible sprouts

4 - The pattern of sprout growth in store

5 - The tuber yield produced in the field

The eye number of tubers of a given weight was shown to be inversely related to tuber K and the rate of increase of eye number with tuber weight was inversely related to tuber N.

A tuber dormancy bioassay was developed which showed that the tubers contained two acid inhibitors which were active in delaying sprouting. The level of the one assumed to be abscisic acid, as measured by a wheat bioassay, was highest in tubers from unfertilized plants. The level of the other, as measured by the intensity of fluorescence under u/v radiation, was highest in tubers with a high N/K ratio. This compound was tentatively identified as a β glycoside of scopoletin, and the observed differences in time of sprouting and the proportion of eyes sprouting explained in terms of the known activity of scopoletin and its glycosides.

Sprout growth rate increased and the symptoms of correlative inhibition decreased with increasing tuber N.

The differences in the yield produced by the seed tubers were related to seed tuber N rather than stem number per seed tuber,

although there was some evidence for a depression in stem number related to high seed tuber K and an increase in branching related to low seed tuber N.

The early yield differences were equivalent to an increase in 1 ton per acre on a 6 ton crop.

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INTRODUCTION

I : Introduction

I i : The importance of the seed potato

In the U.K. about 700,000 tons of seed potato tubers are planted every year. Each acre planted requires about one ton of seed, and each ton costs about £30 if imported from one of the traditional seed producing area (Cox, 1967). Thus seed for a potato crop is bulky and expensive.

Part of the expense is a direct attribute of the bulk, because this implies large handling, storage and transport costs. Another part is the result of the need to produce the seed in an aphid-free environment to prevent the spread of virus disease. This also involves careful (and therefore expensive) management, since the source of viruses must be eliminated by "roguing" diseased plants. Because the traditional aphid-free seed producing areas, such as those in Scotland and Northern Ireland, are remote from the main growing areas, for example Lincolnshire, this increases the cost of transport even more.

In non aphid-free areas it is possible to produce healthy seed if suitable anti-aphid precautions are taken (Broadbent et al 1957) and home production of seed is the biggest single action the grower can take to reduce the cost of ware production (Cox 1967). This eliminates the cost of long-distance transport, but passes the cost of management and bulk storage from the seed producer to the ware grower.

Any management practice, therefore, which will help both the seed production specialist and the occasional seed producer to increase the potential performance, as seed, of a given bulk or weight of tubers, would be of commercial importance. Some such practices are summarized below.

a) Practices producing changes after production of the seed tuber

Choice of size of seed piece

As well as being bulky, potato tubers are also very variable in size. For example Plaisted (1957) studied the growth of tubers with weights varying from 2 to 200 g., and a range of 1 to 500 g. has been found for the early variety "Craigs Alliance" during this study. Since a large part of the cost of seed potato tubers is a result of its bulk, then if tuber size altered the potential yield of a given weight of seed tubers determining the smallest sized tuber concomitant with an economic performance would be logical practice, and the relationship between seed tuber size and yield has therefore been intensively studied.

One of the first studies was by Arthur (1892) on the effects on yield of varying the number of eyes, and the weight of seed piece, planted per hill. Using cut seed, he showed that doubling the number of eyes on a given weight of seed piece planted per hill increased the resulting stem number by a factor of 1.2. Doubling the weight of seed piece planted for a given eye number per hill increased the stem number by a factor of 1.5. As he had also shown that yield per hill was proportional to stem number per hill over the range he studied (4.3 to 11.0 stems per hill), he concluded that weight of seed piece "is a very important factor..... the number of eyes per piece is immaterial". The relationship between yield and stem number per hill has since been verified in the UK, by Bates (1935) using whole tubers of the maincrop variety "King Edward" to achieve a range of 2.2 and 3.8

stems per hill, and by Moorby (1967) using cut tubers of the early var. "Arran Pilot" and the maincrop varieties "Majestic" and "King Edward" to achieve a range of 1 to 18 stems per hill.

These relationships were established for individual hills using fixed hill populations and varying weights of seed tubers. Commercially, the important relationships concern varying populations of hills in a fixed area, and since the cost of seed is directly proportional to the weight of seed, varying the hill population produced from a fixed weight of seed tubers is a more practical exercise. Arthur's results can be re-interpreted in this light. Thus, instead of doubling the weight of seed piece planted for a given area he could have kept the <u>total</u> weight planted constant but halved the size of the individual pieces planted. The following results have been calculated using his data.

Wt. of piece (g)	No. of stems per piece	Stems/decigram
20	4.0	2.00
40	4.9	1.22
80	7.3	0.91

Thus doubling the weight (and the cost) of seed by increasing the size of seed piece from 40 to 80 g. increases the stem number from 4.9 to 7.3. Keeping the weight (and the cost) of seed piece constant per area, but halving the weight per hill from 40 to 20 g. and doubling the hill population would have resulted in doubling the population of hill at 4.0 stems per hill, i.e. 8 stems compared with 7.3 stems at

the doubled seed rate, or 4.9 at the lower seed rate. Thus, there would almost certainly have been an increase in yield at no extra cost. This approach has been followed by Bleasdale (1965) who concluded that for maincrop varieties, the individual size of seed used to establish a given stem density had little effect on performance, if the results were interpreted using the stem rather than the hill as a unit. Generally, the increased plant density which results from using smaller individual seed tubers has greater effects on graded yield than on total yield (Bleasdale and Thompson 1965), the number of very large tubers produced decreasing as density increases. This is important when large quantities of a given grade are required e.g. small tubers for canning.

It has also been shown that "growth rate per stem is inversely related to the number of stems per plant, the stems of single-stem plants growing more rapidly than those of multi-stem plants, which are subjected to a greater degree of competition both for nutrients supplied initially by the mother tuber and for all the resources of the environment" (Ivins and Bremner 1965). Ing (1966) noted that when lifted early, small whole seed of the early var. "Arran Pilot" did not yield as well as large whole seed planted at the same distance and it is normal practice for early production to use as large a seed as economically possible, with few sprouts, to achieve rapid growth of the crop.

Thus, using these two relationships, between stem number and

yield per unit area for a maincrop, and between stem number and stem growth for early crops, the performance of a given population of seed tubers may be modified by changing the size of the individual piece planted. This can be done either by cutting seed, or by choosing the size of seed tuber planted. Both involve extra handling of the seed and therefore extra cost.

Choice of storage temperature

It is well established that the different sprout development required for early and maincrop varieties can to some extent be achieved by controlling the storage temperature. In a comprehensive review, Burton (1966) summarizes the general principle that single sprouting may be achieved by using a high storage temperature to break dormancy and produce conditions favouring apical dominance, whilst multiple sprouting can be produced by using a lower storage temperature which prevents this dominance occurring. By definition, some degree of temperature control is required for such practices which again adds to the cost of the seed.

b) Practices producing changes during seed tuber production

Choice of site of production

Once the factor of virus disease has been eliminated, there is some evidence for different seed performance attributable to climate. Thus, in Poland, Kozlowska (1960) grew two varieties for two years at two different sites, one with an altitude of 207 m and average temperature of 16.3°C, the other with an altitude of 1292 m and a temperature of 10°C but he concluded that the single plant yields of the seed crop were reduced by about 50 g for every 100 m above 300 m that the seed crop was grown. On growing tubers from these sites on the same lowland locations the tubers from the mountain region gave the highest yield. No details were given of tuber size. However, it was concluded from an experiment in the U.K. (Goodwin et al, 1966) that growing the early var. "Arran Pilot" at three sites of latitude 50°44', 52°54' and 55°55' had little consistent effect on early yield provided the seed was well sprouted before sowing. It is possible that the average temperatures of these sites were too close for any difference to be detected, assuming that the temperature difference noted by Kozlowska was the critical factor. Such differences, assuming they exist, will be of little practical importance until significant amounts of seed are produced outside the traditional aphid-free areas, which have a lower mean temperature than areas in which aphids are found.

Choice of fertilisers

The only previous work found relating to this aspect was that done in Eastern Europe. As part of a more comprehensive experiment, Birecki (1960) grew one first early, one second early and one late variety with and without 30 kg. N, 30 kg. P_2O_5 and 40 kg. K_2O per hectare at two sites in Poland. When crops were grown from these two sources of tubers, plants grown from the tubers which had been fertilized in the previous year produced yields 1.4, 3.1 and 2.8% greater than those from plants of previously unfertilized tubers. These very small differences were not significant. Pfeffer (1959) grew three varieties without fertilizer, with balanced high or low fertilizers and with a high N fertilizer. Yields from the progeny of plants from the high, balanced fertilizer treatment were 90% more than those of progeny from the untreated control in one year, but only 18% more at another site in the following year. This discrepancy was explained on the basis of different soil types (light sandy, as compared with fertile loess) although no details were given on differences in climatic conditions in the two years, or on standardization of seed tuber size.

In a report of an experiment designed primarily to examine the interactions of fertilizer treatment and storage temperature on aspects of the biochemistry of the tuber, Alten (1960) noted, in passing, yield differences due to previous fertilizer treatment. Similarly, Wuenscher, (1952), having designed an experiment to examine the effect

of various fertilizer treatments of the seed crop on the insect and virus resistance of the subsequent crop, noted yield increases due to heavy fertilizer application in the first year when an aphid attack failed to develop.

Two Russian reports, both from Lysenko's Institute, claimed positive results. Karmenov (1960) reported a 10% (1940 kg./ha.) yield increase in the second year achieved by applying 30 tons of FYM + 60 units of P and 40 units K per hectare to the seed crop. In a basically biochemical study, Kruzhilin and Shvedskaya (1956) also noted a 23% increase in yield in an early potato variety following N fertilization and a 12% increase following P fertilization. This was explained on the basis of acquired characteristics.

Thus, there is evidence that the fertilizer treatments of parent potatoes sometimes effects the performance of their progeny. A detailed study seemed justified, since the problem had not been clearly defined in previous work (for example, no references were made to standardization of seed tuber weight, or numbers of eyes or sprouts on the tubers) and this in itself would provide a useful basis for comparing different seed lots and for managing varieties displaying the extremes of such characteristics.

I ii : The experimental programme

It was clear that it would be impossible to get very far towards a full understanding of such a problem in a three year period, for two reasons. One was that each experiment would by definition take two years, thus limiting the field work on a problem which would require a long-term study before the considerable interaction of field environment with differences in tuber performance produced by cultural methods (Toosey 1964) could be elucidated. The other was that "seed tuber performance" is a very general term and it would have been naive to expect to find a simple relationship between it and some single factor related to nutrient treatment. At this stage, therefore, it was considered that the primary aim would be to define the problem, which had not been done before, with the explanation of any differences as a secondary aim.

Bearing these points in mind, when planning the programme the first step was to break down the general concept of "performance" into more specific units. This was done by summarizing the two year cycle of seed production and use, and noting the possible physiological effects that nutrient treatment might have on this cycle.

Table

Possible effects of nutrient treatment of the potato on factors likely to affect the performance of its progeny

Event	Possible effects
Seed production	Differences in seed tuber (1) Reserves per eye (2) Composition and availability
Seed performance	Differences in seed tuber sprouting Differences in crop (1) Emergence (2) Stem Number per hill (3) Yield a) Total tuber weight b) Tuber number

When phrased in this way, the concept of "performance" of a tuber can be considered as comprising its sprouting behaviour, time of emergence and number of stems produced by it, and the final yield from these stems. All these aspects have been previously studied individually, but not as an integrated whole. It was assumed that the cause of any differences would be due to quantitative or qualitative changes in the seed tuber reserves pereye (and thence sprout and stem).

A general question was therefore posed at this stage:-

"Can all the differences in seed tuber yield performance attributable to previous nutrient treatment be explained on the basis of differences in stem number per tuber, or do other aspects of performance contribute?"

Four main areas of study were therefore planned. They were:-

1) The eye number/tuber weight relationship.

2) Dormancy and sprouting.

3) Sprout growth in store.

4) Stem growth and yield in the field.

The whole programme was planned as three integrated series of experiments, each covering two seasons, namely 1965/66, 1966/67 and 1967/68. In practice this was not possible in the first series as the tubers, collected from outside sources and not intended for seed use, were found to be infected with virus and with "Blackleg" (Bacterium phytopthorum) which subsequently resulted in the loss of another potato experiment planted by the Physiology Section at Wellesbourne in the 1966 season.

The work on each area noted above and the implications of the results will be presented in the next four sections and then the complete programme discussed as an integrated whole in the final section.

THE EYE NUMBER/TUBER WEIGHT RELATIONSHIP

2. The eye number/tuber weight relationship

2 i): Introduction

Whitehead et al (1953) state "Morphologically, the tuber is a shortened, thickened, stem with scale leaves, and in the axils of these leaves lie the eyes. Each eye is a collection of buds lying more or less in a depression. Actually, the eye is a lateral branch with undeveloped internodes. Thus it will be seen that the tuber is a branched shoot system and not a simple shoot. At the rose end, or apex, of the tuber, the eyes are more crowded than at the heel, or stolon, end". Artschwager (1924) studied the distribution of the eyes on the tuber. He concluded "the eyes in their entirety show a definite arrangement in the form of a spiral, the direction of propagation of which is according to the variety and the individual, either left or right - the apical eye cluster is commonly not in direct line with the main axis but excentric".

Various authors have studied the inter-relationship between size of seed piece, eye number and stem. The work of Arthur (1892) has already been discussed. Bleasdale (1965) using whole seed tubers of varying weights to achieve a range of eye numbers, established linear relationships between eye to sprout number per tuber, and stem number in mid season. He also established a more complex relationship between these parameters, and tuber weight and tuber surface area. Surface area is difficult to measure rapidly and consequently tuber weight is the most commonly used measure of tuber size in studies

of this type, Thus Svensson (1966), as part of a very comprehensive analysis of the sources of variation within seed tuber samples, statistically analysed the relationship between tuber weight and eye number, and found for given samples there was a positive correlation. This was by no means absolute, however, and he concluded "variation in eye number per tuber is also dependant on other factors and it is evident that complete control of variation in number of eyes per seed tuber cannot be obtained by controlling the variation in seed tuber weight."

The present study began before this work was published. It had already been decided that previous nutrient treatment could be another factor affecting the variation in eye number per tuber, and in fact Svensson suggests that work should be carried out on the effects of such treatments on seed tubers. This possibility was therefore examined. Details are given of seed crop treatments in appendix 6.

2 ii): Preliminary studies

The first objective was to establish a method for describing the eye number/tuber weight relationship. Two methods were tested. The first was that used by Bleasdale (1965), which involved selecting four sets of 30 to 50 tubers, closely matched for weight, and counting the eyes on each tuber. A factor, postulated as the minimum eye number per tuber, was subtracted from the mean eye number, and the remaining eye number plotted against the mean tuber weight on a log. scale. This gave four points which fell on a straight line.

To test this method, three samples were taken of tubers of the maincrop var. "Majestic" harvested from plants grown at three widely differing spacings - this was part of an experiment carried out by the Physiology Section at Wellesbourne to study the effect of plant spacing on graded yield. It was felt that the range of densities had been sufficient to produce differences in nutrient level, and that this might be a useful technique for future work. The tubers were washed, and the eyes counted. It was found that the simplest way to do this was to hold the tuber between fore-finger and thumb, rose end uppermost and count the eyes along the spiral described by Artschwager (1924) from heel end to rose end. Each eye was marked with a pencil or felt-tip pen to avoid counting the sameeye twice. It was difficult to distinguish between the eyes at the rose end and this may have introduced a small error. However, to ensure that this error was constant, the counting of the eyes was carried out by one person, rather than introduce the laborious process of individual examination of each tuber under the binocular microscope. The total eye number was written on the tuber which was then weighed to the nearest decigram. This procedure was adopted for all subsequent work.

Four sub-samples of about 30 tubers, closely matched for weight were selected from each of the three main samples, and the mean tuber weight and eye number calculated. When a constant, 3.6 was subtracted from the mean eye number, as done by Bleasdale (1965), and this plotted against mean tuber weight, the overall linearity of the

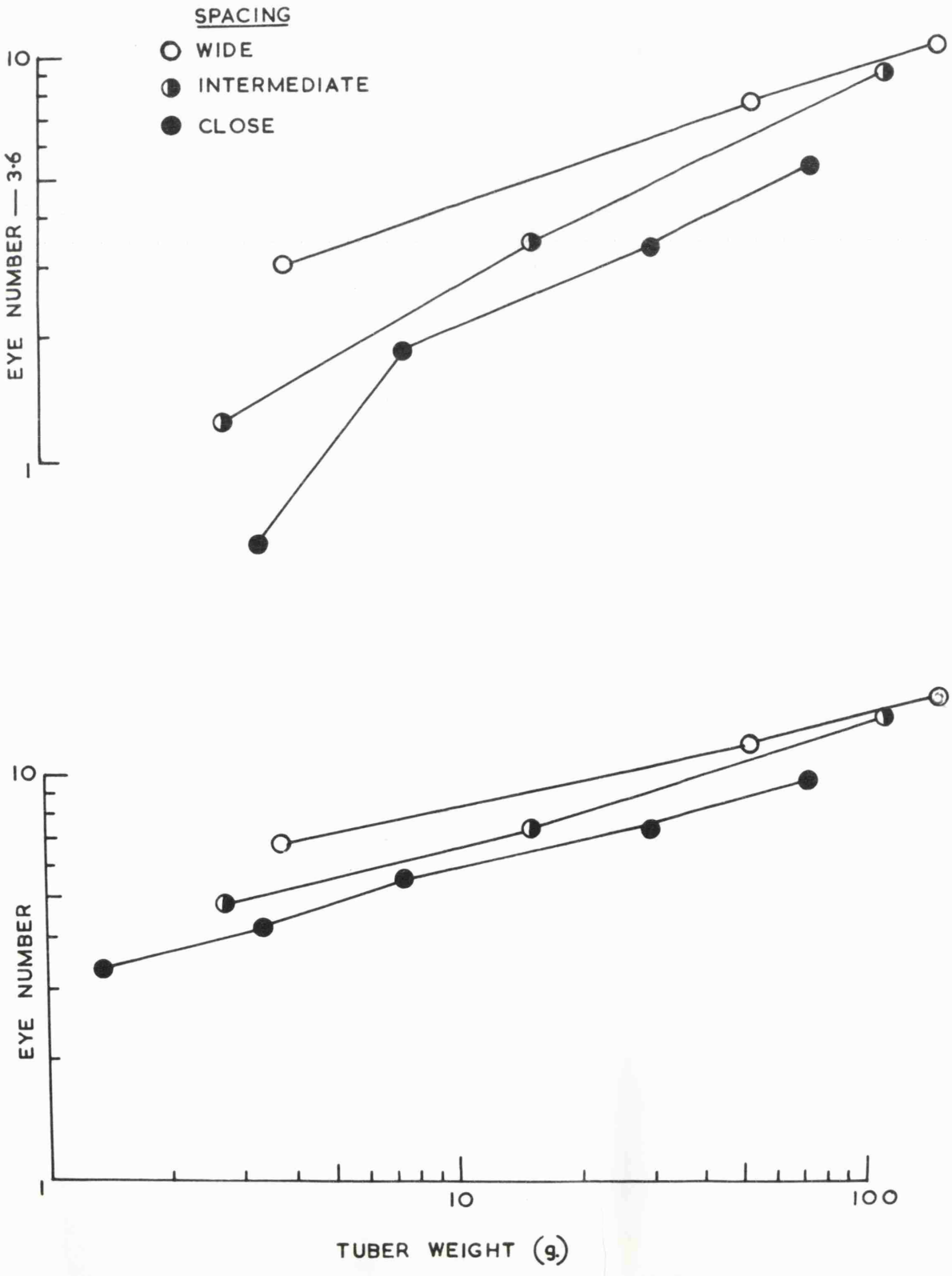
relationship was not as good as that between mean eye number alone and tuber weight (Fig. 1). This was due to two sub-samples of small tubers produced at the highest plant density, with mean weights of 1.4 and 3.4 g. This was less than half the weight of the smallest tuber used in the published work. This could be taken to indicate a more complex relationship between tuber weight and eye number at low tuber weights.

The second method was a statistical approach. It was considered that as log. eye number was related to log. tuber weight, it should have been possible to define the regression ~~time~~ line of these two variables in terms of its coefficient (or slope) and possibly its intercept for given tuber populations and then use these to make comparisons between populations. A computer program was therefore written in EMA by R. Mead of the Statistics Section, which enables the regressions to be fitted by computer (see Appendix 1). It was tested using the data from one computer sample of the "Majestic" material (Table 1) and this verified that subtracting a factor from the eye number did not improve the relationship if the factor was greater than 0.5 (Table 1). Since the improvement was so slight and the physiological implications of 0.5 eyes per tuber were not obvious, it was decided not to use a factor when comparing populations from different nutrient treatments.

These comparisons were made on data collected from small samples of the maincrop var. "Record" which had been grown under eight

FIG. 1

Fig 1 : Determination of the eye number/tuber weight relationship - tubers of maincrop var. 'Majestic', 1965 from plants grown at 3 spacings


SPACING
WIDE
INTERMEDIATE
CLOSE
10
1
EYE NUMBER — 3·6
10
1
EYE NUMBER
10
100
TUBER WEIGHT (g.)

fertilizer treatments at the E. Midland headquarters of the N.A.A.S. These samples were much smaller than those used to establish the method, and therefore the RSS were correspondingly larger. However, the slopes of these regressions appeared to be related to the levels of N and K applied (Table 2 and Fig. 2). Thus the slopes of regression from the balanced treatments, Nil and NPK are almost equal, at 0.253 and 0.267 respectively, whilst those for tubers from treatments NP and K were 0.158 and 0.351 respectively. This difference was statistically, very highly significant. This means that the NP treatment produced tubers in which the eye number/tuber weight relationship was the least log. linear.

Table 1

Fitting the log. eye no./log. tuber weight regression by computer

Constant	Var. about mean	RSS	RSS x 100 / Var. about mean
0	9.6482	3.7767	39.13
0.5	12.107	4.7280	39.05
1.0	15.991	6.2918	39.35
1.5	23.500	9.6267	40.96

Data from 689 tubers of maincrop var. "Majestic". The last column indicates the % variation remaining after fitting the regression.

FIG. 2

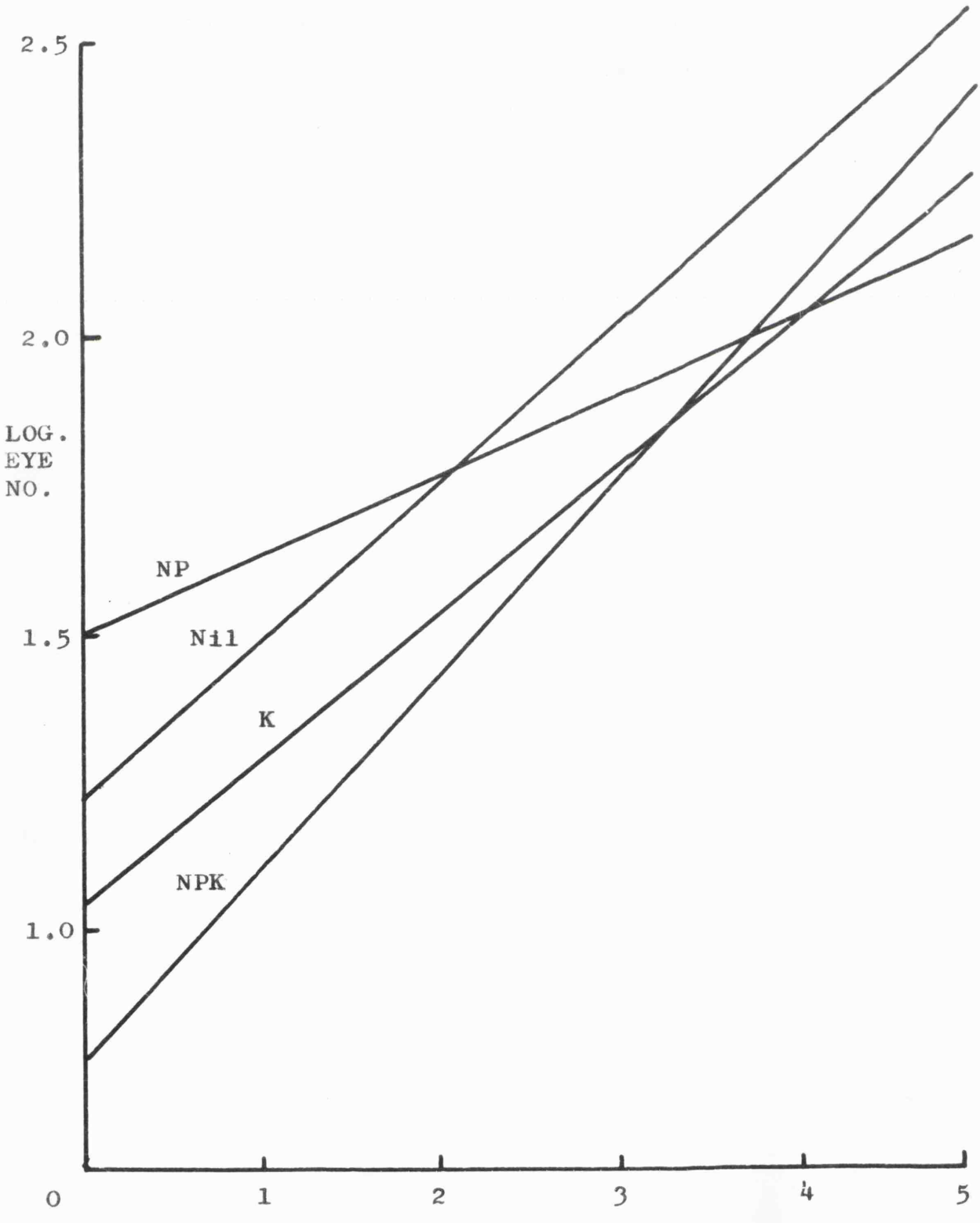
Fig. 2 : Effect of previous nutrient treatment on log. eye number/log. tuber weight regressions

A) Data from maincrop var. 'Record' 1965

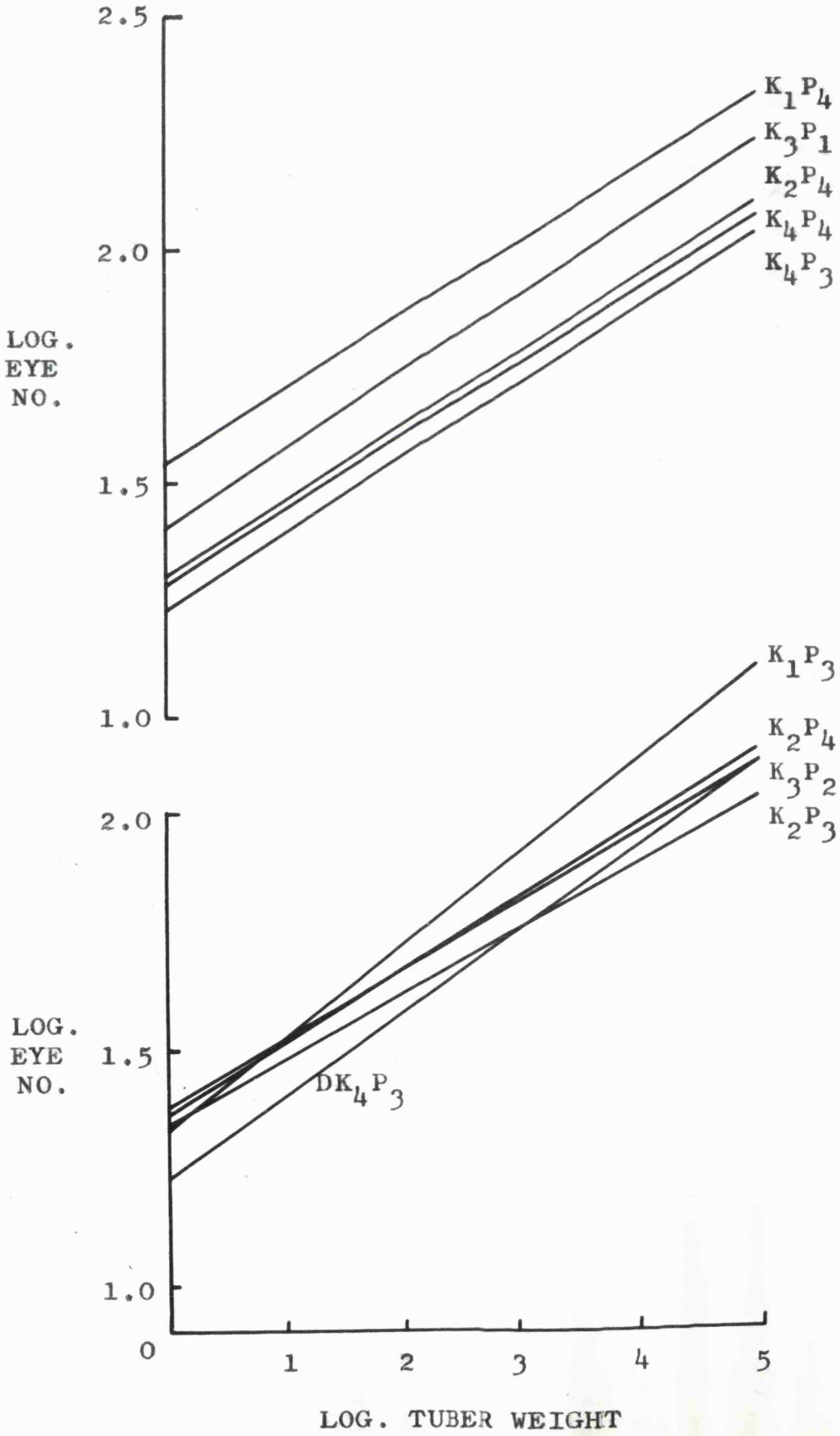
B) Data from early var. 'Craigs Alliance' 1966

C) Data from early var. 'Craigs Alliance' 1967

A



B


2.5
2.0
1.5
1.0
LOG.
EYE
NO.
K1P4
K3P1
K2P4
K4P4
K4P3
K1P3
K2P4
K3P2
K2P3
2.0
1.5
1.0
0
LOG.
EYE
NO.
DK4P3
1
2
3
4
5
LOG. TUBER WEIGHT

C

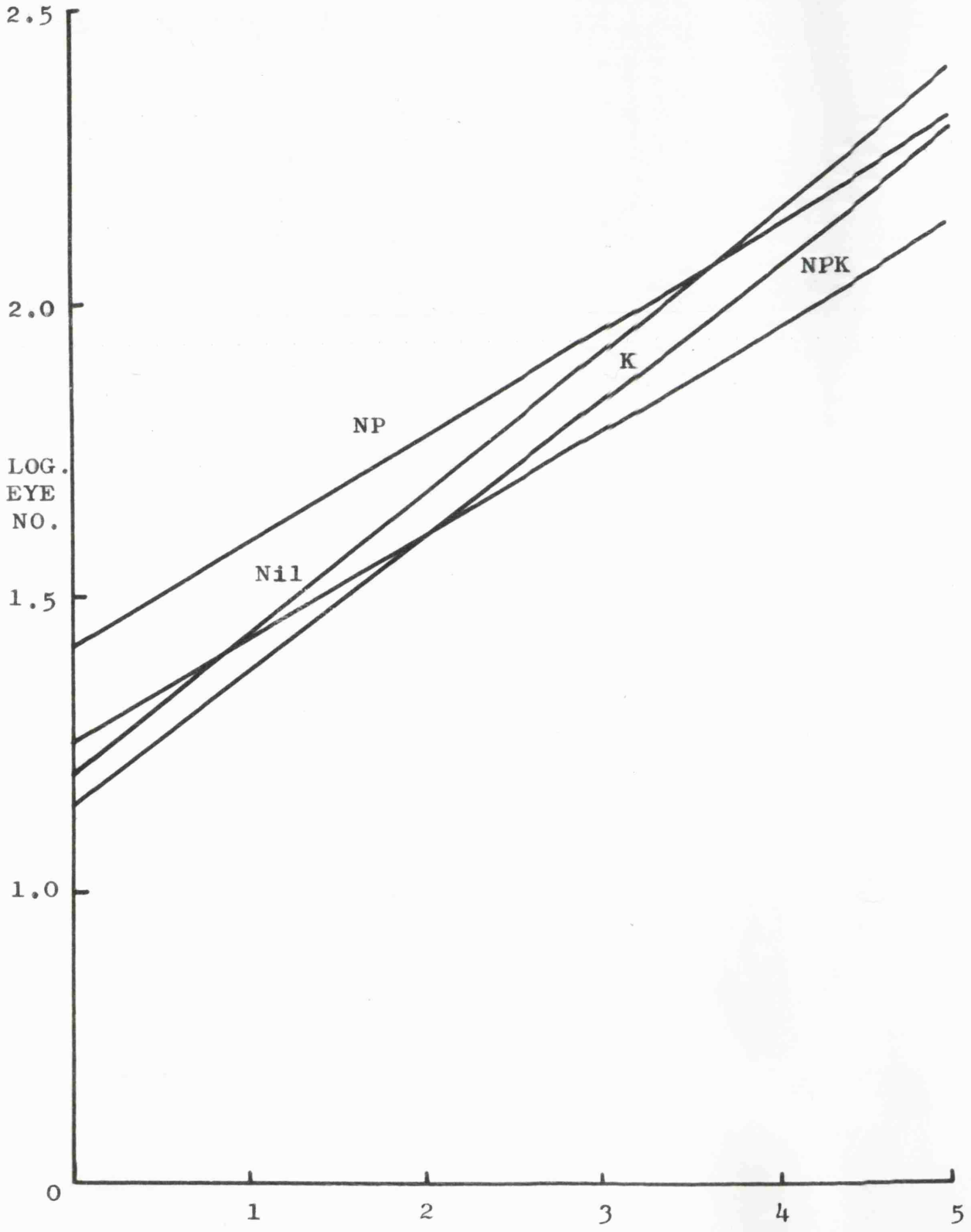


Table 2a

Effect of nutrient treatment on log eye no./log. tuber weight regression

Treatment	Tuber No.	Slope	Intercept	RSS x 100 Var. about mean
NPK	101	0.267	0.946	66.2
NP	55	0.158	1.388	85.9
NK	104	0.263	1.015	69.8
PK	79	0.278	1.031	54.2
N	89	0.228	1.272	75.6
P	53	0.264	1.129	82.4
K	62	0.351	0.686	47.0
Nil	48	0.253	1.118	64.0

Data from tubers of maincrop var. "Record"

Table 2b

Statistical comparison of the regressions produced from treatments NP and K

A common regression was compared with the two individual regressions, and the difference in the sums of squares removed compared by calculating the variance ratio of the two sums.

		^{o}F	MS	VR (=F)
RSS common regression	27.392	115		
" individual "	2.472	113	0.0218	
Difference	24.920	2	12.460	568.9

'F' value	'F' (P = 0.05)
568.9 *	3.1

N.B. All statistically significant calculations will be noted with an *. The magnitude of the significance can be judged from the required values, which will be quoted for each calculation.

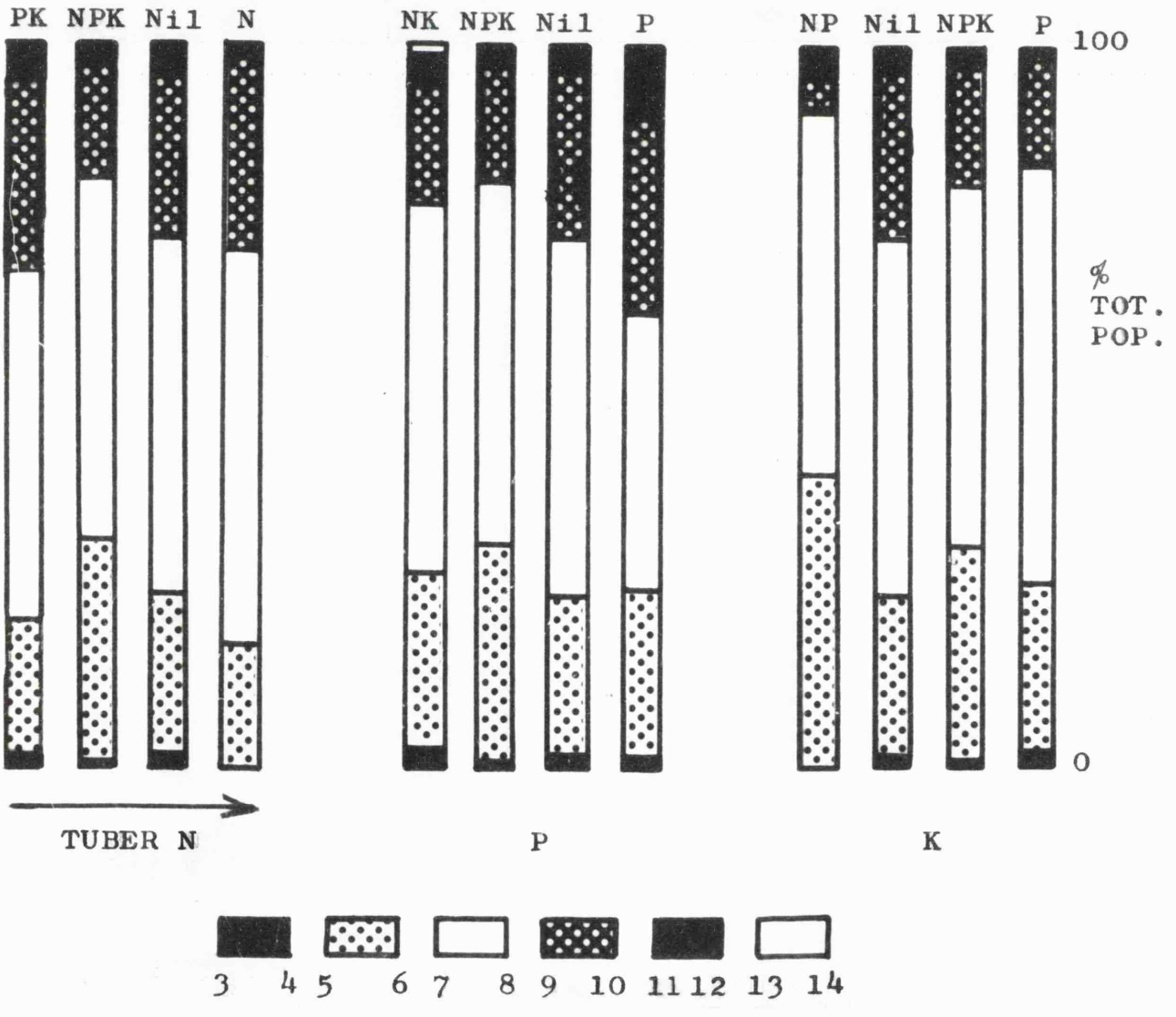
This could have been due to a greater proportion of small tubers in this treatment, producing an effect similar to the effect of close spacing previously noted. Since the regressions for tubers from the balanced treatments were almost parallel, in practical terms this meant that there had been a tendency for tubers of the same weight from the NPK treatment to have fewer eyes than from the unfertilised control. Details of the computer print-out are given in Appendix 3a.

Such changes could have been produced in two ways. It was noted in the introduction that the tuber can be considered as possessing a spiral of eyes, becoming more closely spaced at one end. Thus shifts in the distribution of tuber weight within a given eye number, and in the number of tubers of a given eye number regardless of weight, could both produce changes in the relationship due to the amount of tubers produced per eye, and in the actual number of eyes produced. These possibilities were studied by re-examining the data from which the regressions were calculated, constructing bar charts showing the % of the individual tuber populations with a given eye number, and then calculating the mean tuber weight for a set of eye numbers. (Tables 3a and 3c, Fig. 3).

It was decided that it would be more realistic to relate any such changes to differences in the levels of N, P and K in the tubers, rather than to the fertilizer treatments applied to the soil. Samples of the tubers were therefore analyzed by the Chemistry Section (see Appendix 2), although it was realized that for N and P this would give

FIG. 3

Fig. 3 : Effect of N, P and K on the distribution of eye number per tuber - maincrop var. 'Record' 1965


PREVIOUS
TREATMENT
PK NPK Nil N
NK NPK Nil P
NP Nil NPK P
100
%
TOT.
POP.
0
TUBER N
P
K
3 4 5 6 7 8 9 10 11 12 13 14
CLASS INTERVAL FOR EYE NUMBER

no indication of any relative differences in the amounts of the numerous substances containing N and P in the tubers.

The results confirmed the importance of K, since the trends in eye number distribution related to tuber N and P are the inverse of that for tuber K, whilst the K fertilizer treatment was the only single element treatment which produced tubers with a mean weight greater than the unfertilized control; this is demonstrated by the first steps of the standard calculations to demonstrate main interactions in a factorial experiment shown in Table 3b. It was also apparent that changes in the relationship were due to changes both in eye number and tuber weight.

These studies had shown that it was feasible to compare the effects of nutrient treatments on the relationship by regression analysis (although the coefficients so obtained were rather low), and that the level of tuber K was important in determining the value of this coefficient. It was therefore decided to study the effect of K in more detail.

2 iii) <u>The effect of K</u>

It was considered at this stage that as the influence of the seed tuber is greatest in the early stages of growth (Denny 1929), an early variety might be more likely to provide positive results from this type of study, and in a shorter growing season, than a maincrop variety. Also, as different varieties probably have different fertilizer requirements (British Atlas of Potato Varieties 1965) it

Table 3a : Effect of nutrient treatment on mean tuber weight at 6 eye numbers - data from maincrop var. Record 1965

Eye No.	Treatment							
	NPK	NP	PK	P	NK	N	K	Nil
5	37.0	25.5	21.9	31.8	21.3	16.9	23.9	23.0
6	35.6	26.9	24.6	27.1	34.3	24.1	29.3	25.7
7	38.3	28.3	45.8	34.3	38.2	30.5	35.1	33.3
8	55.0	40.6	47.3	32.0	47.5	32.5	49.0	47.7
9	72.0	58.4	50.5	32.1	57.0	35.2	58.0	49.4
10	85.7		67.9	40.3	66.5	47.8	97.7	39.2
Σ	323.6	179.7	258.0	197.6	264.8	187.0	293.0	218.8
$\bar{x}$	53.9	35.9	43.0	32.9	44.1	31.2	48.8	36.5

Table 3b : Effect of nutrient treatment on mean tuber weight at 6 eye numbers

Scheme of calculations for finding the treatment main effects and interactions

Treatment	Tuber weight	(1)	(2)	(3)	Main effects
Nil	36.5	+ 85.3	160.6	326.3	
K	48.8	+ 75.3	165.7	53.3	K = 13.33
N	31.2	+ 75.9	25.2	3.9	N = 0.98
NK	44.1	+ 89.8	28.1	8.5	NK = 4.25
P	32.9	+ 12.3	-10.0	5.1	P = 1.28
PK	43.0	+ 12.9	13.9	2.9	PK = 1.45
NP	35.9	+ 10.1	0.6	23.9	NP = 11.95
NPK	53.9	+ 18.0	7.9	7.3	NPK = 7.3
	326.3				

As there was no replication in the experiment, the complete analysis of variance was not possible.

Table 3c : Tuber nutrient levels and mean tubers weight at 6 eye numbers

Effect of N

N (% D.M.)	0.95	1.51	1.69	2.17
Mean tuber weight (g)	43.0	53.9	36.5	31.2
Treatment	PK	NPK	Nil	N

Effect of P

P (% D.M.)	0.18	0.20	0.25	0.25
Mean tuber weight (g)	44.1	53.9	36.5	32.9
Treatment	NK	NPK	Nil	P

Effect of K

K (% D.M.)	1.23	1.44	1.71	2.13
Mean tuber weight (g)	35.9	36.5	53.9	48.8
Treatment	NP	Nil	NPK	K

was decided to use a variety which would respond well to fertilizers, with the intention of magnifying any differences in seed performance due to fertility. The final choice was the early var. "Craigs Alliance", since it was known to be susceptible to low fertility and was also related to the var. "Craigs Defiance" shown by De (1960) to continue responding to very high levels of applied K.

The variety was grown during the 1966 season in a series of plots comprising a long term P/K factorial experiment conducted by the Chemistry Section at Wellesbourne. The treatments consisted of four levels of K ranging from 0 to 800 units K_2O per acre factorially combined with four levels of P ranging from 0 to 400 units P_2O_5 per acre. Each treatment included a basal dressing of 100 units N per acre apart from one completely unfertilized control. This series of 16 treatments was repeated with the addition of 30 tons of F.Y.M./acre making 32 treatments in all. Each plot measured 10 ft. x 5 ft., and so it was decided to plant on the flat to utilize the ground area more efficiently. 50 seed tubers were planted in each plot on a foot square grid.

During the growing season, the haulms were regularly sprayed with a proprietary insecticide, "Metasystox", to control aphids and thence insect-borne virus disease, and also with a tin-based fungicide, "Du-ter" as a prophylactic against "Blight" infection. These precautions appeared to have been effective, although no pathological tests were made.

The inner set of 32 hills of each plot was harvested in October after all the haulms had died down, producing very approximately 100 - 200 tubers per plot. Unfortunately many of the tubers were infected with "scab" which made eye counting even more difficult and almost certainly introduced inaccuracies which added to the high level of variability already expected.

It is difficult to estimate the value of drawing conclusions from such data - see Fig. 2b. For instance two sets of data are presented in Table 4 (details, Appendix 3b) both of which comprise regressions from tubers with a similar range of mineral contents. The first series corroborates the conclusions of the preliminary studies, namely than an increase in tuber K levels reduced the intercept of the regression (that is, reduced the number of eyes on a given weight of tuber) and also increased its "goodness-of-fit". No such relationship was apparent in the second series, and so no statistical comparisons were made and no conclusions were drawn until further experiments had been carried out.

2 iv) The effect of K and N

In the 1966 experiment, the levels of K added were changed against a constant level of N. In 1967 studies were made on the effects of changes in fertilizer K related to changes in N. Accordingly, four of the basic fertilizer treatments used in the preliminary study were adopted, namely NPK, NP, K and an unfertilized control. This gave two balanced fertilizer treatments, one high and

Table 4

Effect of K on log. eye no./log. tubers wt. regressions

Treatment	Tuber nutrients				Slope	Intercept	RSS x 100 Var. about mean
	N *	P	K	K/N			
K_1P_4	1.58	0.33	1.36	0.86	0.1604	1.5432	69.0%
K_3P_1	1.41	0.26	2.25	1.60	0.1461	1.4107	62.0
K_2P_4	1.27	0.28	2.05	1.61	0.1609	1.3065	61.0
K_4P_4	1.74	0.29	2.84	1.63	0.1741	1.2800	53.3
K_4P_3	1.38	0.29	2.71	1.96	0.1765	1.2329	45.4
K_1P_3	1.79	0.34	1.31	0.73	0.1935	1.3691	61.2%
K_2P_3	1.44	0.28	2.22	1.58	0.1306	1.4403	77.9
K_2P_4	1.27	0.28	2.05	1.61	0.1609	1.3065	61.0
DK_4P_3	1.65	0.40	2.98	1.81	0.1310	1.4912	72.0
K_3P_2	1.30	0.28	2.58	1.98	0.1091	1.4840	71.6

Data from early var. "Craigs Alliance" 1966.

* % D.M. Means of 2 analyses of bulked dry material from tubers of widely differing weights

one low, and also one high N and P/low K treatment, and one high K/low N and P treatment.

Four replicates of each treatment were planted, in ridges, with 15 ridges each of 25 plants per replicate. Two points of technique warrant detailed description.

1 : Fertilizer placement

As this was the first year of application of the fertilizer treatments, a method of placing the fertilizer was used, since placement is now considered good practice for potato management (Cox 1967) and can increase crop responses by up to 150% (Cooke et al 1954).

When applying fertilizers, a common practice at Wellesbourne is to broadcast the requisite amount as evenly as possibly over the plot either by hand or using a proprietary hand-pushed applicator. However, it is clear that some of the nutrient is initially positioned above the seed and roots and whilst this may not be critical for a mobile element such as nitrogen which is quickly leached into the soil, it could markedly affect the response to the less mobile elements, phosphorus and potassium. This problem is to some extent overcome in long-term experiments (such as at the Shardlow Hall fertility demonstration) with repeated tillage and application of the same treatments. Such an approach was not possible in the limited time available. The placement method devised was as follows

a) The requisite amount of fertilizer required for each plot was calculated, then divided into 13 portions, one for each ridge in the plot.

b) The plots were marked out using the tractor-drawn tool bar carrying four ridging bodies set at a steep angle to the ground and at such a height that the shares just skimmed the surface.

c) The set of 13 very shallow furrows so formed were divided into 25 feet long plots, with a two feet wide path in between each plot, and the fertilizer was then applied as evenly as possible by hand to these furrows.

d) The ridging bodies were then set at the correct angle and height, and a second tractor run made, off-set by half the distance between the bodies, to produce ridges over the furrows.

e) The tops of the ridges were then flattened with a light roller, and the seed "pot-holed" in, at a spacing within the ridge of 1 ft.

f) A further "ridging-up" was carried out when the haulms had emerged.

The recommendation for a fertilizer band for potatoes is 3 ins. to the side and 3 ins. below the seed (Tisdale and Nelson, 1966). Basically this arrangement produced a band approximately 4 ins. directly below the seed. However, the variation within a ridge almost certainly resulted in a reasonable amount of fertilizer being in the optimum position.

Differences in haulm growth resulting from the nutrient treatments were very distinct and uniform (Plate 1) although how much these differences were accentuated by the fertilizer placement is

impossible to judge.

2 : Sampling

By eliminating five plants from each ridge at harvest (two guards and any obviously diseased plants), the yield from 20 plants was left. This gave a useful sample size with an inherent variation in tuber number and individual weight which was related to treatment. This was considered to be more realistic than the alternative which would have been to bulk all the tubers harvested from each treatment, and then take samples at random.

Tubers from two such samples were weighed and counted, and the regressions calculated for each (Table 5, Fig. 2c, Appendix 3c). Considering the inherent variation in the relationship, the regression coefficients or slopes replicated well, as did the intercepts to a lesser degree. The differences between the intercepts of the regression from NPK and NP were shown to be significantly different.

In interpreting the differences between treatments, the regression produced by tubers from treatments NPK and NP, and those from treatments K and Nil can be considered as two pairs, those from treatments K and Nil having a greater slope than those from the other two treatments. It was observed in the field that the haulms of plants produced under treatment K and Nil were small and pale green, and therefore both probably suffering from N deficiency. Both treatments NPK and NP produced luxuriant dark green haulms - this can be seen from Plate 1. In addition, the haulms grown under treatment

PLATE 1

Plate 1 : Effect of nutrient treatments on haulm growth of the seed crop

The central section of the photograph shows 8 different treatments. Reading from foreground to the far background, these are:

NPK, NP, Nil, K, Nil, K, K, NP.

It is impossible to distinguish between treatments NPK and NP (the luxuriant haulms in the foreground) but the marked difference between these and the next 5 N deficient treatments can be clearly seen. It is also possible to distinguish between the very poor haulm growth under the Nil treatment, and the slightly more vigorous, but still pale, haulms of treatment K.

NP were demonstrating the classic "bronzing" symptoms of K deficiency late in the season. A summary of the chemical analyses is given in Table 5c. It seems reasonable, therefore, to suggest that a) the regression slope is inversely related to N rather than positively related to K, since there is a significant difference between the slopes of the NPK/NP regressions and the Nil/K regressions, and b) the intercept is inversely related to K, since the intercept for the regression from tubers produced under conditions of K deficiency produced by treatment NP is significantly higher than the regression from the NPK material.

Table 5a : Effect of N and K on the log. eye number/log. tuber wt. regression

Treatment		N	P	K	K/N	Slope	Intercept	RSS x 100 Var. about mean
NPK	1	1.56	0.23	1.87	1.20	0.1745	1.2545	27.0
	2	1.47	0.18	1.86	1.27	0.1636	1.3373	41.3
NP	1	1.70	0.24	1.21	0.71	0.1777	1.4170	38.4
	2	1.56	0.18	1.32	0.85	0.1603	1.5328	50.1
K	1	1.07	0.26	1.90	1.78	0.2269	1.1526	34.7
	2	0.99	0.22	1.83	1.85	0.2240	1.0679	30.0
Nil	1	1.15	0.25	1.79	1.56	0.2363	1.2089	47.3
	2	0.96	0.26	1.85	1.93	0.2294	1.0887	47.5

Table 5b

Statistical comparison of regressions from treatments NPK and NP (high N pair) and from treatments Nil and K (low N pair)

NPK and NP - i) : Common slope and intercept

	SS	^{o}F	MS
Total SS	1575.068	407	
CF	1536.970	1	
Slope	22.760	1	22.76
RSS	15.328	405	0.038

ii) Common slope, different intercept

Total SS	1575.068	407	
CF	1537.640	2	
Slope	25.060	1	25.060
RSS	12.370	404	0.031

When comparing i) and ii):-

'F' value	'F' (P=0.05)
96.7 *	3

Similarly for treatments Nil and K, F = 9.9 *

Table 5c : Chemical analyses of tubers from 1967 seed crop

	Treatment				
	NPK	NP	K	Nil	l.s.d. (P = 0.05)
N	1.56 *	1.70	1.07	1.19 ± 0.11	0.22
P	0.23	0.24	0.26	0.28 ± 0.01	0.03
K	1.87	1.21	1.90	1.79 ± 0.10	0.21
K/N	1.20	0.71	1.78	1.50	

* Each value is the overall mean of 2 sets of 10 analyses done on individual tubers weighing 30 - 35 g and 60 - 70 g

2 v) **Discussion**

The objective of this series of experiments was to see whether previous nutrient treatment would affect the eye number/tuber weight relationship. That this was the case is clear from the results presented, although to arrive at precise conclusions is more difficult. To facilitate this, the objective can be usefully widened to include the effects of environment on this relationship. Thus it was shown in the preliminary studies that plant density could alter the relationship, high planting densities tending to reduce the number of eyes on a given tuber weight. Bleasdale (pers. comm.) has evidence that increasing the plant density has little effect on the K levels in the tubers, but there is a progressive reduction on tuber N levels, resulting in an overall increase in the K/N ratio. This agrees with all the results shown here including one of the experiments with (sets of) the rather variable results of 1966. Following on from differences in tuber K and N produced by plant spacing, it is feasible that similar differences can be produced by other environmental changes such as temperature during the growing season. The experiments of Kozlowska (1960) have already been mentioned. He grew potatoes for seed at a range of sites up to 840 m above sea level, and correlated a decrease in yield of the seed crop with altitude of the site and an increase in K content. The relevant point is that when the seed tubers so produced were grown on, there were differences in yield depending on the source of seed. Had there been some estimate of the

eye numbers and tuber weights of the various seed lots, this might have revealed some consistent differences. Apparently no such measurements were made.

To condense these considerations into a practical statement relevant to seed production and use is difficult since the regression lines were not all parallel, and therefore by definition sometimes crossed. This would mean that in some cases a treatment effect could cancel itself over a particular range of tuber weights. However, there was a tendency for tubers produced under conditions which resulted in a high tuber K or K/N content to have fewer eyes for a given weight than tubers with a high N or low K/N content.

The tendency for some treatments to reduce eye number would only be of practical use, however, if there was a corresponding reduction in sprout number and thence stem number. It was also possible that previous nutrient treatments could have an additional effect on the time of appearance of the sprouts and their subsequent growth. These topics were therefore studied in the next stage of the investigation.

3

DORMANCY AND SPROUTING

3 : Dormancy and Sprouting

3 i) Introduction

a) Definitions : After seed tubers have been harvested, there is usually a delay of up to several months before sprouts become visible. If a variation in the duration of this delay were produced by previous nutrient treatments, it could affect seed performance. Whilst Audus (1963) frequently compares the lack of bud growth in the potato with that in tree buds during dormancy, Vegis (1964) states "Whether true dormancy occurs in potato tubers has not been definitely ascertained." The considerable literature on the subject has been summarized by Burton (1963, 1966). In this, Davidson (1958) is quoted: "The appearance of a readily visible sprout is not a sign of dormancy break but the first visible indication of growth which has been progressing from the time of harvest." Davidson used the mean growth rate from several eyes to obtain the data on which his conclusion was based, and this has been criticized by Goodwin (1967) who noted only irregular spasmodic growth of individual sprouts during dormancy, which when expressed as a mean appeared to indicate slow continuous growth. In his comments on Davidson's work, Burton (1963) states : "It is quite possible for a sample of potatoes at 10°C to produce visible sprouts within a week or so of harvest and for these sprouts then to grow vigorously. It is equally possible that some months will elapse after harvest before the production of visible sprouts, but the rate of growth may then be as great as in the first sample. If the whole process from a sprout

0.5 mm to, say, 30 mm long takes the same length of time in the two situations, are we not justified in ascribing to something we may describe as 'dormancy' a difference of perhaps 8 or 10 weeks in the time needed for the appearance of a sprout 0.5 mm. long." These comments have been quoted at length, because distinction between the production of visible sprouts and the process of sprout growth is relevant here. It is quite possible that previous nutrient treatments could produce situations in which the time of appearance of sprouts 0.5 mm long differed markedly, as did the length of time for the sprouts to grow to a length of 30 mm. It was decided, in view of these considerations, to relate the time of appearance of visible sprouts to the previous nutrient treatment of the tubers and to consider subsequent sprout growth as a separate topic.

b) Dormancy "break": If the time of appearance of the sprout is considered to be the result of an event initiating its growth, then this event must have preceded the sprouts appearance.

One such event is the disappearance of inhibitors from the peel of dormant tubers at the time of sprouting. The theory that acid inhibitors play a major part in the maintenance of tuber dormancy was first suggested by Hemberg (1949) and subsequently developed by his team (Hemberg 1958, Marinos and Hemberg 1960 and Boo 1961). The development of the work has been criticized by Burton on several grounds, an important one being the use of Avena coleoptile straight growth assay as a test for compounds active in maintaining dormancy when this is a plant system which exhibits no dormancy. Since

Hemberg's first paper, paper partition chromatography has been developed and used to isolate many plant growth substances including inhibitors (e.g. Bennet-Clark, 1952). Using paper chromatography, Kefford (1955) showed Hemberg's acid inhibitors to be identical to the Inhibitor β complex of Bennet-Clark (loc. cit.). A group of neutral inhibitors was also noted in the extracts, but since the levels of these sometimes can rise at dormancy break (Hemberg 1958) they are not considered to be implicated in the maintenance of dormancy.

Intensive study on a range of plants by Wareing and his team (Frankland 1961, Eagles and Wareing 1964, Robinson and Wareing 1964, Cornforth et al 1965, El-Antably et al 1967) has shown that most of the activity of the inhibitor complex was due to a substance then called dormin. Since its isolation, characterization and synthesis it has been shown to be identical to abscisic acid first isolated by Addicott et al (1964) from young cotton fruit.

Another almost parallel development has been the implication of gibberellic acid (GA) in the initiation of sprouting. External applications of GA were shown to break dormancy (Rappaport et al 1957), and a flush of endogenous gibberellin activity was detected when sprouts were appearing by Smith and Rappaport (1961). They were unable to determine, whether this flush preceded, or was the consequence of, sprouting, but their data indicates that 30% of the tuber population had sprouted Before the flush of activity. This time sequence was also noted by Kumar (1966), who questioned the role of gibberellins in tuber

dormancy on this basis. As Smith and Rappaport used 1 kg. of tuber peel per extract, probably comprising 40 to 400 individual tubers, their data does not necessarily preclude a causal relationship between the rise in gibberellic activity and the beginning of events leading to the appearance of visible sprouts on individual tubers. Consequently, until rapid screening techniques for gibberellins are developed which can be used on large numbers of single tubers, the exact time sequence of the gibberellin flush related to dormancy break will be difficult to estimate with precision.

The complementary roles of acid inhibitors and gibberellins have been combined by some workers (Boo 1961, Bruinsma 1962) who consider that the ratio of gibberellins to inhibitors is the critical factor in controlling the transition from dormancy to full sprouting capacity. A number of such promotor/inhibitor complexes have been suggested as agents in controlling seed dormancy. These include an abscisic acid/kinin complex controlling the messenger RNA/protease system in the cotyledons of dormant squash seeds (Penner and Ashton, 1967) a coumarin/gibberellin complex in dormant lettuce seeds (Khan and Tolbert, 1966) and a coumarin/kinin complex in dormant rose seeds (Khan and Heit, 1967). In addition, it has been shown that dormancy in potato eyes is probably due to direct regression of DNA (Tuan and Bonner, 1964), and that sprouting in potato eyes requires DNA and RNA synthesis, and the availability of gibberellins (Madison and Rappaport, 1968).

Many other correlations have been made between biochemical changes and dormancy break - these are comprehensively reviewed by e.g. Burton (1966), Emilsson and Lindblom (1963), and Kumar (1966). These include changes in soluble carbohydrates, respiration rates, number of sulphydryl groups, and volatile compounds. The most relevant comment seems to be that of Burton (1963) "In conclusion ..... it seems worth stressing once again that we should look at the physiological and biochemical state of the dormant and the sprouting tuber as a whole. The individual worker can rarely do much more than study one aspect of this whole ..... In contemplating his results, however, he must remember that any substance ..... is but a small part of a complex and interdependent whole."

It was therefore decided to study the levels of inhibitors in tubers from different nutrient treatments in relation to the time of appearance of sprouts as one aspect of the whole subject, in view of their proved importance in the maintenance of dormancy, bearing the above caution in mind.

3 ii) External Symptoms

a) Appearance of sprouts : Presence or absence of sprouts on a tuber was used as one measure of this symptom of dormancy break, thus enabling data to be accurately summarized as a mean or percentage. Accordingly, the tubers used in establishing the eye number/tuber weight relationship were re-examined after various periods in store for presence or absence of sprouts. For the 1966 seed crop, the choice of treatments had to be made before the computer fitted eye number/ tuber weight regressions were available. The treatments chosen were the second set presented in Table 4.

The results of these examinations are presented as a series of bar charts and graphs.

Figs. 4a to c show the relationship between treatment and the % of tubers in the treated population showing sprouts. The data is from three varieties each grown in a different year, and was taken when it was estimated that about 50% of tubers in the median treatment had sprouted.

Fig. 4d demonstrates for the 1967 data the trends with time for this relationship.

The 1965 "Record" data (Fig. 4a) indicates a strong positive effect of K. Thus, of the single nutrient treatments, K was the only one which resulted in a large number of tubers sprouting 12 weeks after harvest - the other single nutrient treatments N and P and also treatment NP, which would all be expected to be low in K, showed virtually no sign of sprouting.

FIG. 4

Fig. 4 : <u>Effect of previous nutrient treatment on the percentage of tubers with visible sprouts at a given time after harvest</u>

A) Maincrop var. 'Record' 1965, 12 weeks after harvest

B) Maincrop var. 'Majestic 1965, 10 weeks after harvest

'Small tubers' = tubers with mean tuber weight 3 g.

'Medium tubers' = tubers with mean tuber weight 60 g.

W = Seed crop grown at wide spacing

I = " " " " intermediate spacing

C = " " " " close spacing

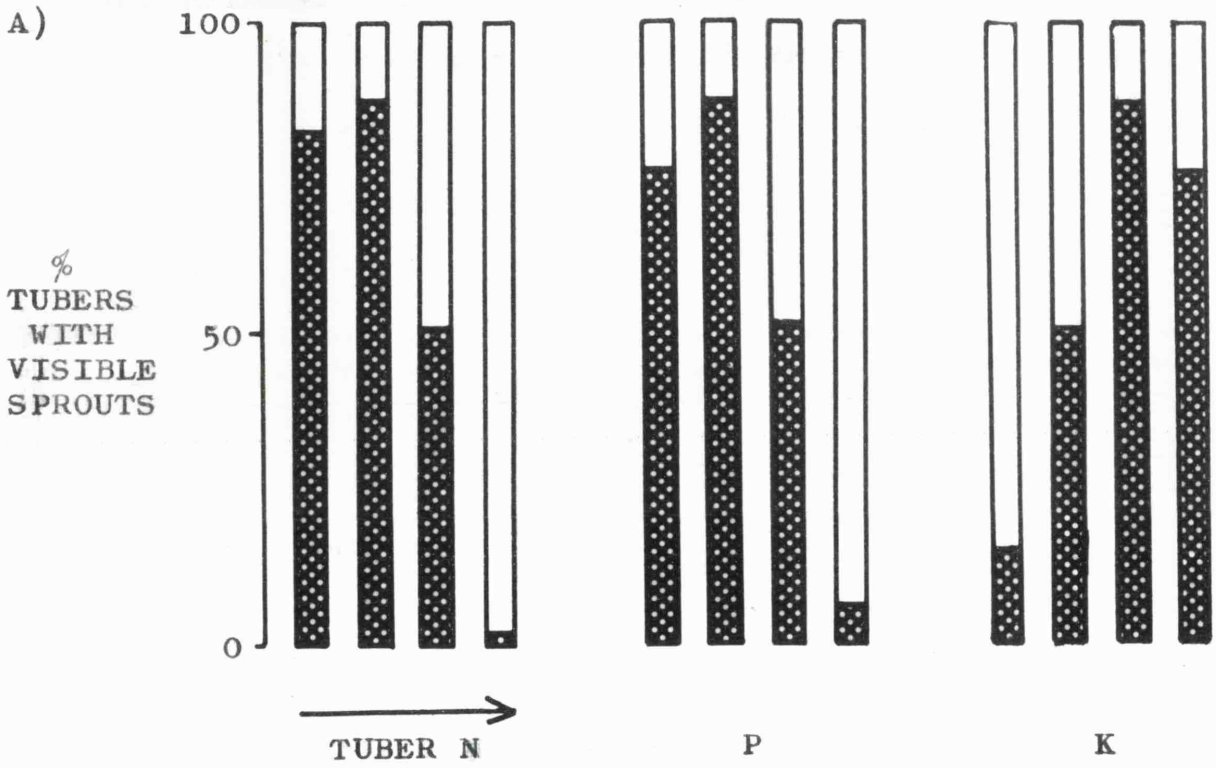
C) Early var. 'Craigs Alliance' 1966, 21 weeks after harvest

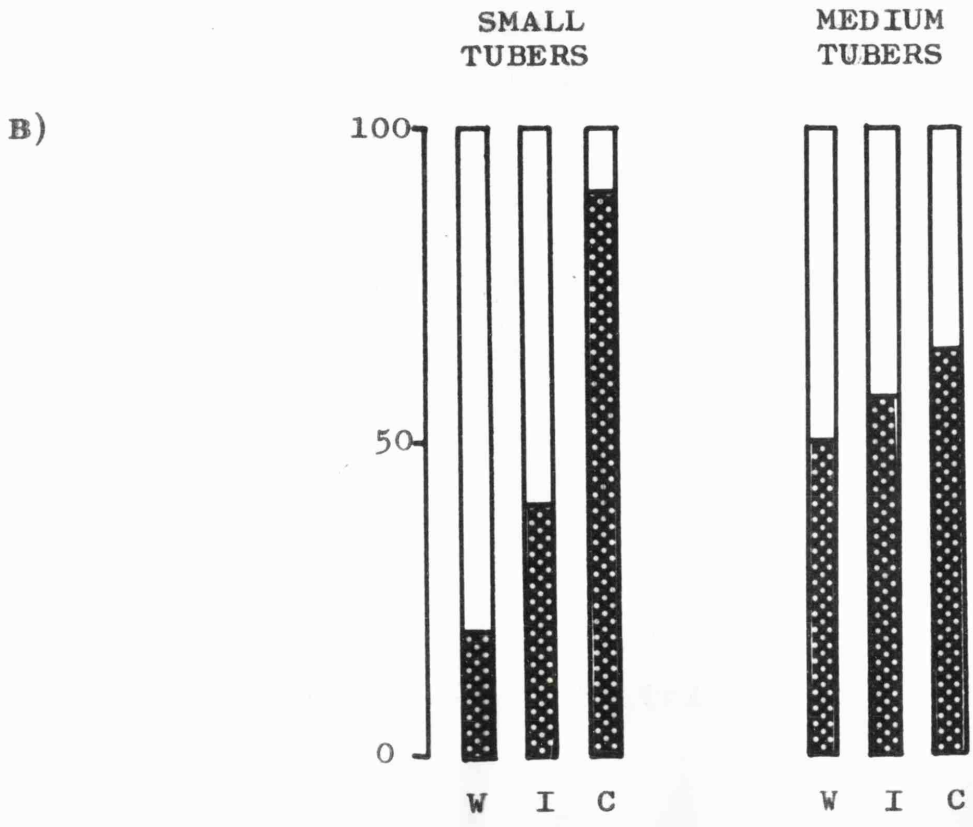
D) Early var. 'Craigs Alliance' 1967, on 3 dates:-

123 days after harvest

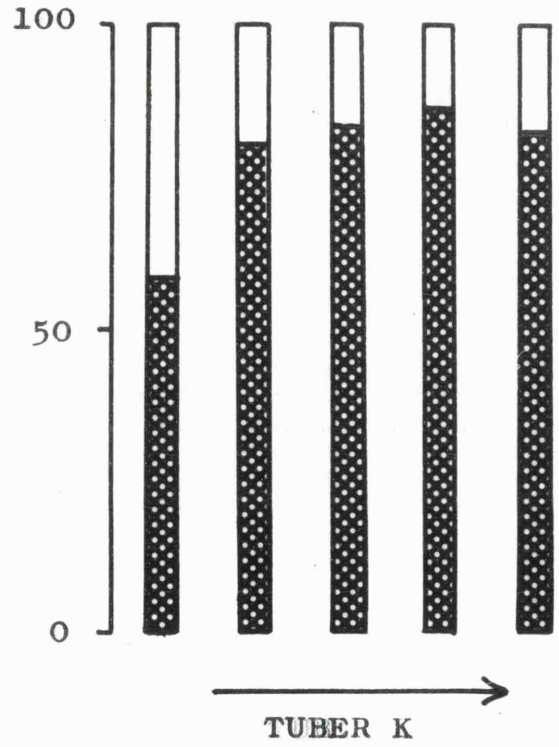
132 " " "

147 " " "

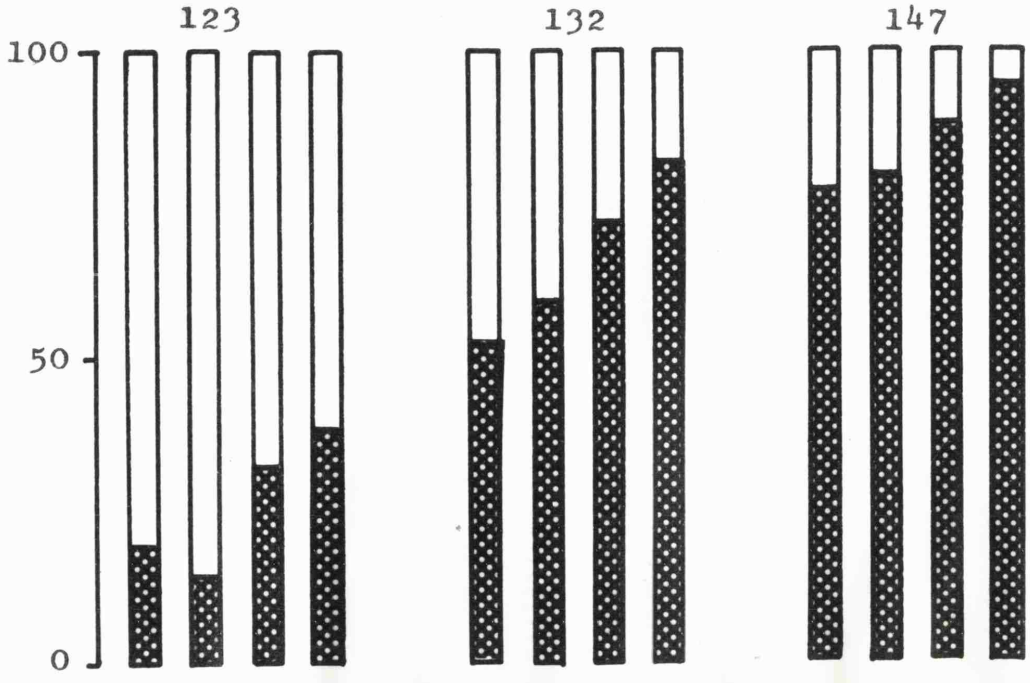

A)
100
50
0
% TUBERS WITH VISIBLE SPROUTS
TUBER N
P
K


SMALL TUBERS
MEDIUM TUBERS
B)
100
50
0
W I C
W I C

C)



D)



With the "Majestic" data (Fig. 4b) is was possible to estimate the effect of spacing treatments on tubers with widely differing weights. It is clear that the closer the spacing of the parent plants, the more tubers had sprouted 10 weeks after harvest. The trend was more marked with the 3 g tubers. Further, of the tubers produced at the close spacing, more of the 3 g tubers had visible sprouts than the 60 g tubers. Emilsson (1949) found that small tubers had an appreciably longer dormancy than larger tubers initiated at the same time. Burton (1963) envisages this as due to the dilution of a given amount of inhibitor by the larger tubers. Conversely, Toosey (1964) states that "lifting tubers in an immature state accelerates the end of dormancy." There was evidence that the small tubers produced at the close spacing were different in that the eye number/tuber weight relationship was different from that suggested by Bleasdale (1965). These tubers had fewer eyes than expected. It is possible that there had been more than one period of tuber initiation and that these particular tubers were initiated late and therefore harvested immature. Late initiation can occur when there is a return to conditions favourable to growth, the most usual being rain following drought (Whitehead et al 1953). That tuber re-growth did occur is indicated by the large numbers of mis-shapen tubers in samples from the wide spacing, due to swelling at the eyes termed "gemmation" by Whitehead. Spacing had a marked effect on gemmation.

Table 6 : Effect of spacing on tuber gemmation

	Wide	Medium	Close
Mis-shapen tubers	4.3	0.6	0.01
Total yield	11.3	19.0	23.0
% mis-shapen	38	3.2	0.04

Thus virtually no mis-shapen tubers were produced at the close spacing. This could indicate a change in the form of tuber re-growth from a renewal of growth in old tubers to the production of new primary tubers. This is an important point, relevant to the thesis, since different treatments could conceivably alter the magnitude of such tuber re-growth and therefore introduce another source of variation in the data. It does not necessarily change the fact that close spacing of the seed crop accelerated the appearance of sprouts and the implications of this will be discussed in the final section.

1966 data : There was a fairly good relationship between K in the tubers, and time of visible sprouting, Fig. 4c. There was also evidence for an optimum for tuber K, which, when exceeded, delayed the appearance of sprouts.

1967 data : (Fig. 4d) Bearing in mind the possibility that a secondary initiation of tubers might alter the results, the material was examined for evidence of this. Since mature tubers of the var. "Craigs Alliance" have a brown netted skin, it was considered that all small white-skinned tubers were immature (Goodwin 1967, quoting Sabalvoro 1965), and were therefore examined separately. A proportion was found in each seed source:

: Effect of previous nutrient treatment on the number of secondary (smooth) tubers

Seed Source	NPK	NP	K	Nil
Tubers examined	1276	1926	1266	880
Smooth tubers	181	270	143	74
% smooth	14.3	14.0	11.2	8.4

The difference between the NPK and NP sources and the Nil source was not statistically significant, but could be an indication that the more luxuriant haulms produced by the NPK and NP treatments were capable of producing more dry matter late in the season than were the small haulms produced by the Nil treatment. All the tubers examined separately had sprouts visible regardless of size although sprout growth rates were not measured. This might be of commercial interest in situations where either two crops of tubers are grown in one year or where a large number of small tubers are required (as with samples for canning in which case the smooth skin would be an added advantage). Use of irrigation at a stage much later than is normally recommended might be profitable in this instance.

An analysis of variance of the remaining data showed that significantly fewer tubers from treatments NP and Nil were sprouting compared with those from treatment K which in turn were fewer than those from treatment NPK:-

Table 7 : Effect of previous nutrient treatment on the percentage of tubers with visible sprouts 16 weeks after harvest - data from 1967 seed crop

Treatment			
NPK	NP	K	Nil
67.9% *	38.5	64.7	36.5
74.3	38.5	65.0	38.0
80.6	46.0	59.6	49.1
82.5	49.6	72.1	50.5
82.0	48.5	75.6	52.5
77.1	50.0	73.0	42.4
84.7	52.5	65.7	59.5
549.1	323.6	475.7	328.5
78.4	46.2	68.0	46.9 ± 3.2%

* Each value from tubers produced by 20 plants

S.E. of mean = ± 3.2%

L.S.D. (P=0.05) = 7.1%

The trend of these differences with time was followed in two ways. One was to observe the number of tubers sprouting on tubers collected from 20 plants and express the results as a percentage regardless of tuber number or weight. This is shown in Fig. 5a. The other was to correct for differences in tuber weight by observing only those tubers whose weights could be matched in all the treatments. In addition only tubers weighing less than 50 g were used, since the eye number/tuber weight relationship study had indicated that for treatments NP and K at least, differences in eye number were probably greatest at small tuber weights and disappeared at weights above 50 g. This is shown in Fig. 5b. It is clear that the same trend appears using both methods. That is, the tubers from the NPK treatment were consistently advanced compared with tubers from the K and Nil treatments, and tubers from the NP treatment were consistently more retarded. The maximum difference between treatments was about 15 days for the complete samples, and 18 days for the small tubers when compared at the time at which 50% of the tubers were displaying sprouts. The difference was indeed, therefore, accentuated at low tuber weights.

Assuming at this stage that the appearance of sprouts meant that dormancy was being broken, then the fertilizer treatments used produced a difference of the order of two to three weeks.

b) Number of sprouts: The number of eyes sprouting was considered to be the earliest possible estimate of sprout number and thence stem number likely to be produced from a given tuber sample. Some of the

FIG. 5

Fig. 5 : Effect of previous nutrient treatment on the rate of appearance of sprouts - 1967 seed crop

A) Tubers from 20 plants

B) 50 matched tubers, weighing 2 - 60 g.

% of tubers with visible sprouts determined on 6 dates 96-147 days after harvest.

Legend

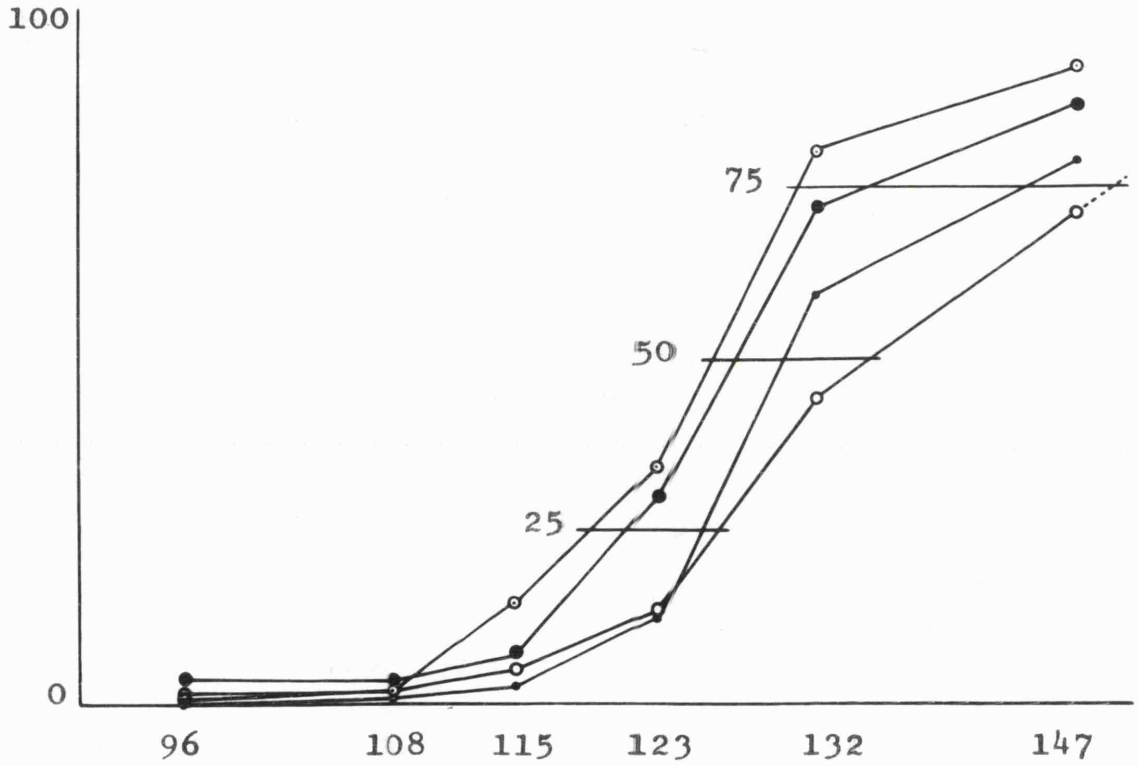
Treatment NPK = Open circle with small dot

" NP = Open circle

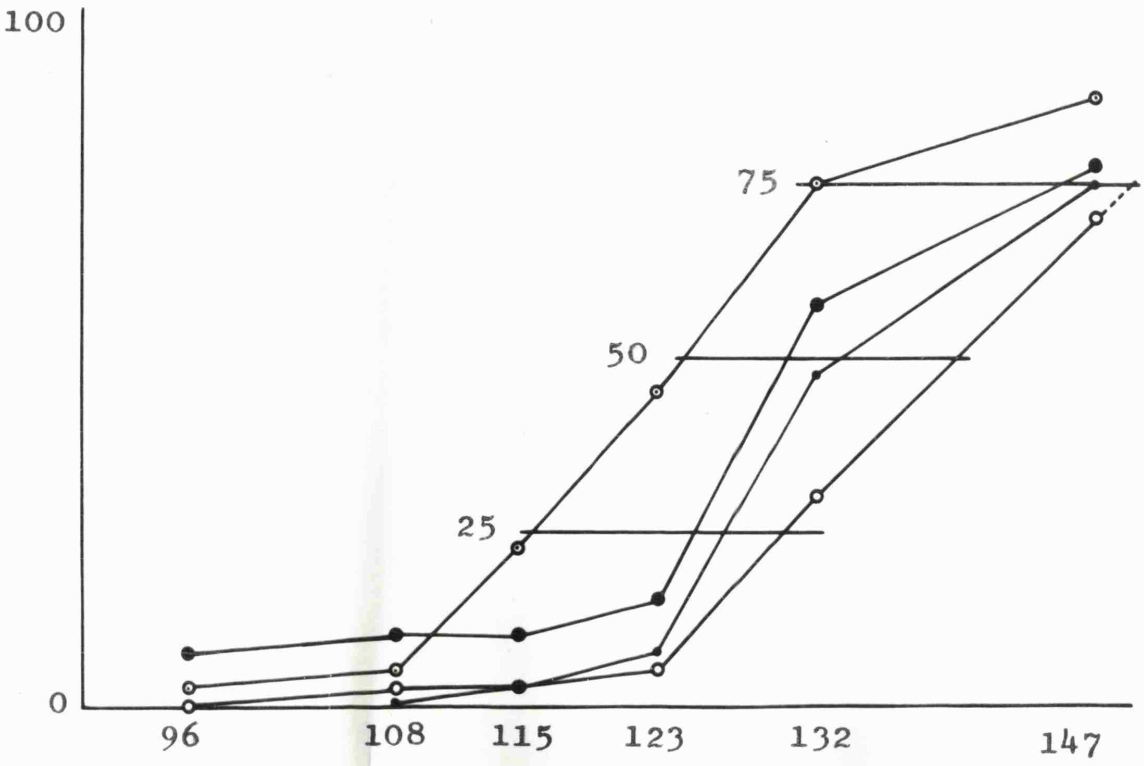
" K = Large dot

" Nil = Small dot

A)


100
75
50
25
0
96
108
115
123
132
147

B)


100
75
50
25
0
96
108
115
123
132
147

material used in the previous section was therefore re-examined, and each eye examined for presence or absence of sprouts. This data is summarized in Figs. 6a-d, further details are given in Appendix 5.

In general, previous nutrient treatment had a similar effect on the percentage of the total eyes sprouting to that on the percentage of the total tubers sprouting. Thus, there was a positive relation with K in all three years, and the 1965 "Majestic" data showed that for small tubers the percentage of eyes sprouting was positively related to the spacing at which the parent material had been grown, whilst this trend was reversed as tuber weight increased.

However, this approach does not account for differences in eye number per tuber between given samples. Accordingly, the 1967 data was re-expressed as the number of eyes on 100 tubers with visible sprouts. These figures are incorporated into Fig. 6d and do not significantly alter the general positive relationship between K and number of sprouts.

The rate of appearance of visible sprouts was also measured. This was done over a 10 day period for data from each sample of the 1967 tubers starting from the point at which 5% of the tubers had visible sprouts (a physiological point) and also at 118 days after harvest (a chronological point). The accumulated percentage eyes with visible sprouts was plotted on a log. scale over these periods, and the rate measured as the slope.

FIG.6

Fig. 6 : <u>Effect of previous nutrient treatment on the percentage of eyes with visible sprouts at a given time after harvest</u>

A) Maincrop var. 'Record' 1965, 12 weeks after harvest

B) Maincrop var. 'Majestic' 1965, 10 weeks after harvest

'Small tubers' = tubers with mean weight 3 g.

'Medium tubers' = tubers with mean weight 60 g.

W = Seed crop grown at wide spacing

I = Seed crop grown at intermediate spacing

C = Seed crop grown at close spacing

C) Early var. 'Craigs Alliance' 1966, 21 weeks after harvest

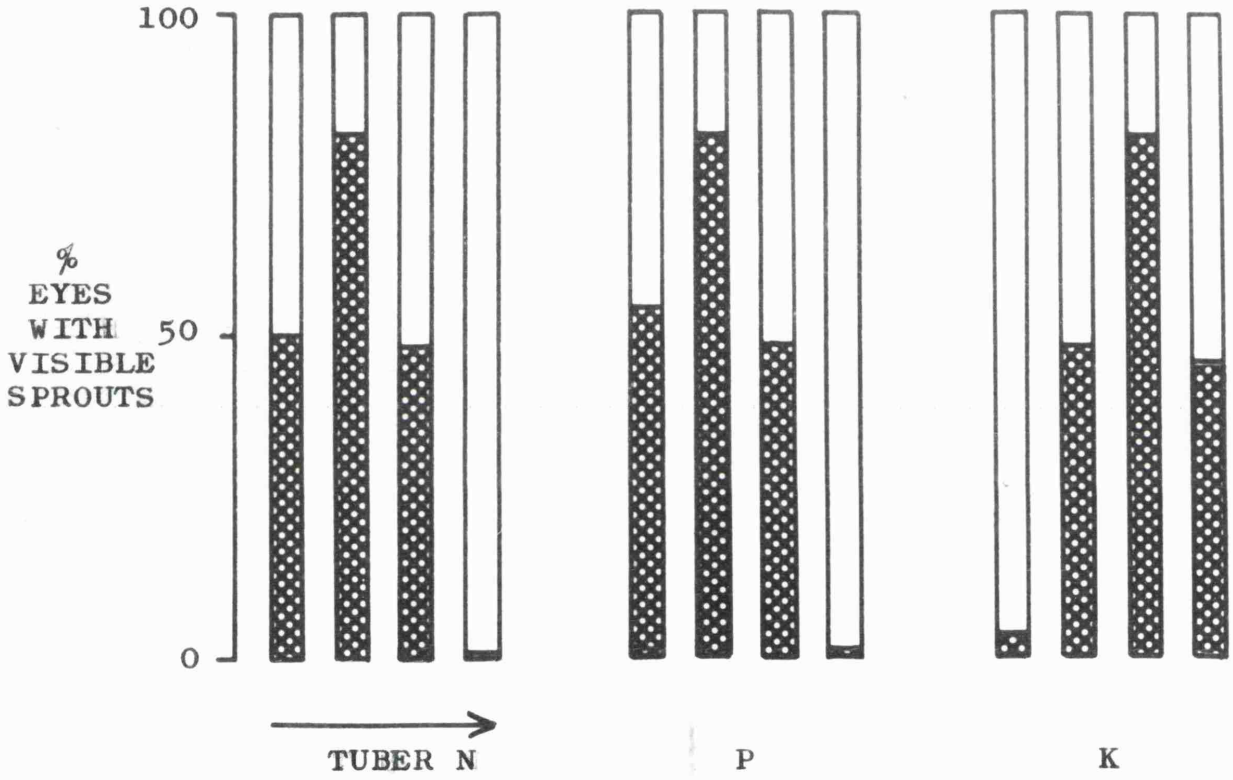
D) Early var. 'Craigs Alliance' 1967, on 3 dates:-

123 days after harvest

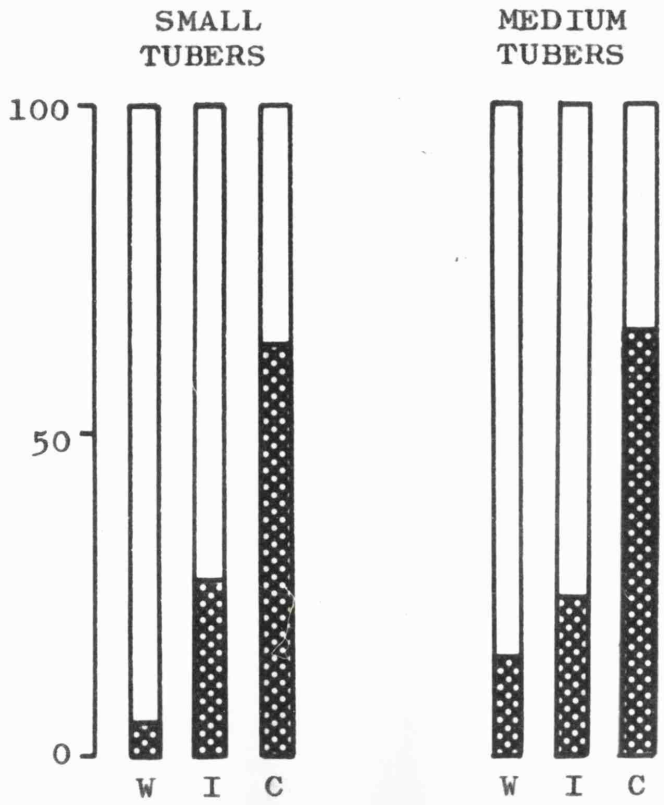
132 " " "

147 " " "

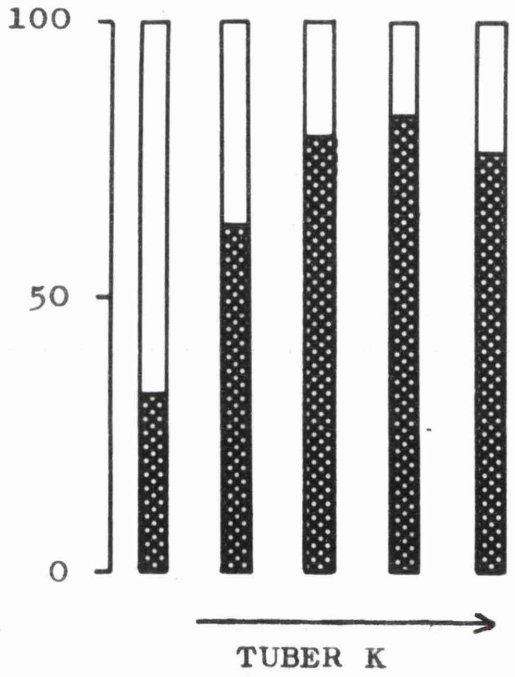
A)


100
50
0
% EYES WITH VISIBLE SPROUTS
TUBER N
P
K

B)


SMALL TUBERS
MEDIUM TUBERS
100
50
0
W I C
W I C

c)


100
50
0
TUBER K

D)

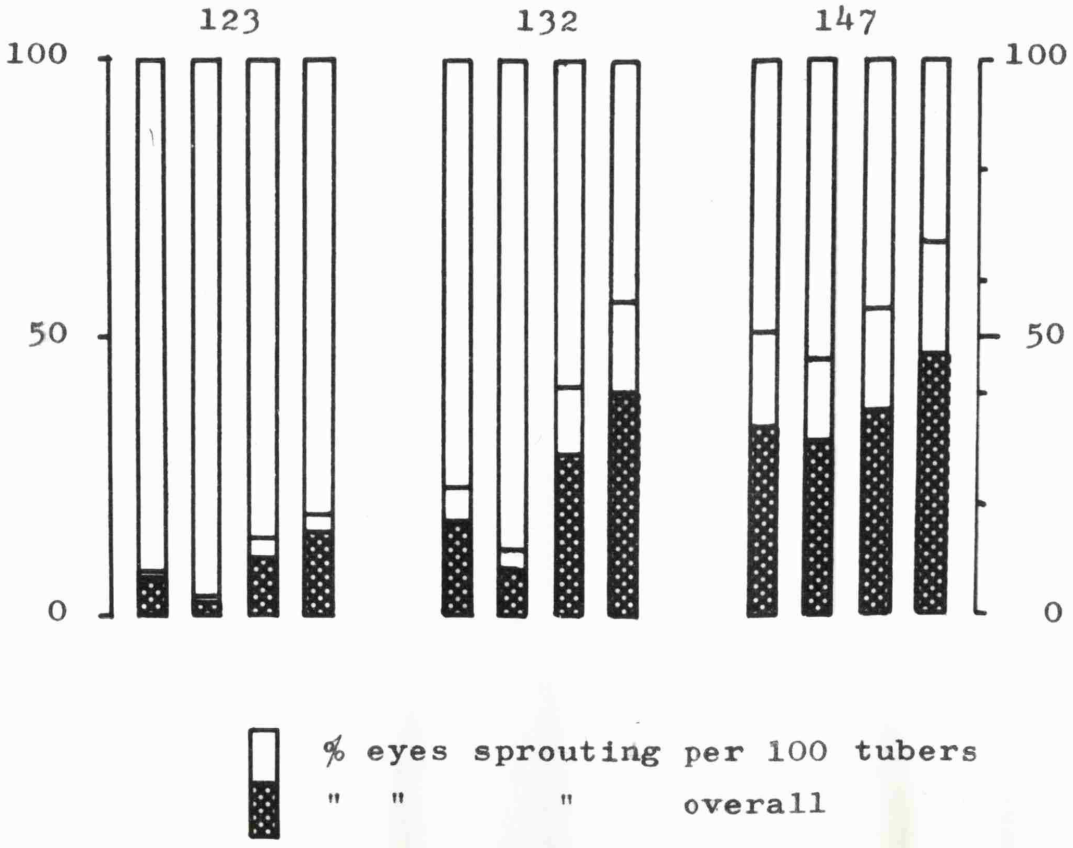

123
132
147
100
50
0
100
50
0
% eyes sprouting per 100 tubers
" " " overall

Table 8 : Effect of previous nutrient treatment on the rate of appearance of visible sprouts - 1967 data

	Treatment			
Rate (% eyes per day)	NPK	NP	K	Nil
10 day period after 5% point	1.0	0.9	1.4	1.5
Period 118 - 128 days after harvest	1.5	0.5	1.3	0.3

This demonstrates that although both treatments Nil and NP produced tubers on which sprouts were appearing less rapidly 118 days after harvest than the other tubers, the rate increased markedly for the Nil treatment once 5% of the tubers had sprouted, whilst the rate for the NP treatment remained low.

3 iii) Internal Symptoms

Having established that differences in the time of appearance of sprouts on seed tubers could be produced by differences in the previous nutrient treatment, it was decided to attempt to establish related differences in the levels of relevant compounds in the tubers. It seemed reasonable to look for differences in the levels of acid inhibitors, mentioned in the introduction to this section, as the action of these compounds forms a major part of current theory on dormancy control.

a) Extraction of inhibitors : Tubers were sampled from the 1967 "Craigs Alliance" seed crop at intervals throughout the growing season and during storage until sprouts had just started to appear. Apart from the first two samples which comprised a large number of very small tuber initials, the samples normally comprised three or four tubers individually weighing 20 - 70 g, giving a total sample weight of 100 - 150 g.

The tubers were macerated in sufficient absolute methanol to be diluted by the water in the tubers and bring the concentration down to 80% and left to extract in a deep-freeze (-4°C) for 24 hours. The brei was filtered, and the filtrate reduced to dryness under vacuum. Lipids and starch were removed at this stage by taking up the residue in the minimum amount of water and precipitating these compounds by adding an excess of absolute ethanol. The extract was then re-filtered and again reduced to dryness. The resulting gum was taken up in water,

and acidified to pH3 with a few drops of 5% hydrochloric acid. The acidic compounds were then partioned into ethyl acetate, the upper acetate layer being separated with a separating funnel and the lower aqueous layer re-partioned twice with fresh acetate. The bulked acetate layers were reduced under vacuum, and the resulting dark brown residue made up to a standard concentration of 20 g tuber fresh weight equivalent per ml. in absolute ethanol. Aliquots of 0.25 ml (5 g tuber fresh weight equivalent) were loaded on strips of Whatman No. 1 paper 5 cm wide, and the papers developed by descending chromatography using an isopropanol : ammonia : water (10:1:1 v/v) solvent system. This was the system used by Bennet-Clark (1952) when the Inhibitor complex was first separated by paper chromatography. After the solvent front had run about 20 - 25 cm (this took about 7 hours) the papers were removed and left to dry. They were then marked out into 10 equal strips between starting line and solvent front by Rf lines (solvent front = Rf 1.0) which were cut up ready for bioassay. If this was no possible, the papers were stored at -4°C until used.

b) Bioassay of inhibitors

The Wheat Coleoptile segment straight growth assay:

The method used was a modification (Thomas, pers. comm.) of the assay developed by Bentley and Housley (1954). It remains one of the most convenient bioassays for attempting quantitative measurements of inhibitor activity (Luckwill, pers. comm.) although its limitations in assaying for dormancy maintenance activity have already been noted.

Grains of the spring wheat var. "Atle" were soaked for 4 hours in water and then scattered on damp wadding in plastic boxes kept in the dark at 25°C. This provided coleoptiles 2 to 3 cms long (and therefore suitable for providing assay material) three days later.

The coleoptiles were picked using forceps, laid transversely along a microscope slide, with the tips along the longest edge, and a sub-apical segment 10 mm long removed using a guillotine constructed for the purpose. Speed at this stage was essential to prevent subsequent curvative due to geotropism. Sufficient segments were cut to provide eight segments for every Rf strip to be assayed, and these were floated in phosphate buffer, pH 6.8, in eight petri dishes. This systematic division of the assay material, ensuring an even distribution of segments of all ages for each Rf. strip, was considered by the author to be an important modification.

The strips to be assayed were placed into rectangular plastic boxes measuring 5.5 cm x 3.5 cm, to which was added 1 ml of phosphate buffer, pH 6.8. Blank chromatograms were run to provide material for the controls. One coleoptile from each petri dish was put into each assay box, making 8 per box. After 20 hours, the segments were removed and measured to the nearest mm. Inhibitor activity was indicated when growth in the presence of a strip resulted in an average coleoptile length less than that of the controls.

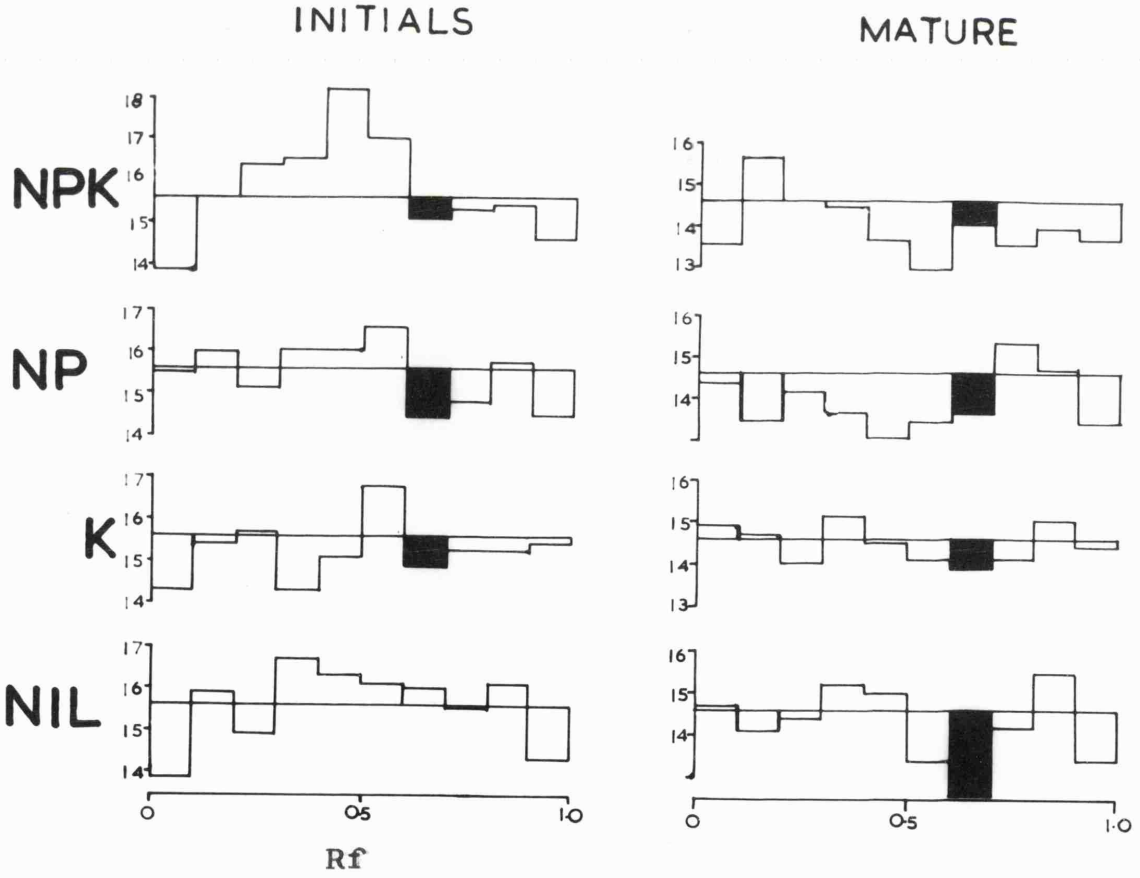
Samples of the results are presented in Fig. 7. These indicated that all the extracts contained a zone of inhibition between Rf 0.6

FIG. 7

Fig. 7 : Effect of previous nutrient treatment on the levels of acid inhibitors in tubers - extracts from 1967 seed crop assayed by Wheat coleoptile segment straight growth assay

'Initials' = tuber initials sampled from seed crop in early June

'Mature'= whole tubers after harvest in early October


INITIALS
MATURE
NPK
NP
K
NIL
18
17
16
15
14
13
0
0·5
1·0
Rf

and 0.7, which is the area of the chromatogram at which the Inhibitor β complex is centred in this system. It also seemed that mature tubers from the "Nil" treatment might have had a higher level of inhibitors. This seed treatment produced tubers with a longer dormancy than the others.

To verify this, an assay was done on this Rf strip from four chromatograms from each extract from tubers which were just beginning to sprout. Non-sprouting tubers had been deliberately chosen to ensure that any differences noted actually preceded the observed differences in sprouting. The results are shown below.

Table 9 : Analysis of Variance of coleoptile segment length after growth in presence of Inhibitor β .

Tuber	Block				Segment length (mm)	
Treatments	1	2	3	4	Total	Mean
NPK	15.2	16.0	16.0	16.0	63.2	15.8 $\pm$ 0.2
NP	16.6	16.5	16.4	16.9	66.4	16.6
K	16.6	16.5	16.4	15.7	65.2	16.3
Nil	15.1	16.0	15.0	15.4	61.5	15.3
Control	18.2	17.9	17.9	18.2	72.2	18.0
Block Total	81.7	82.9	81.7	82.2	328.5	

l.s.d. (P = 0.05) = 0.55

This indicates that there was a significant inhibition of coleoptile growth due to all the extracts when compared with the control and that indeed the highest level of inhibition was in the tubers from treatment Nil. However, it also seemed as if tubers from treatments NP and K

could have a lower level of inhibitors than either of the others. Logically, therefore, these tubers should have sprouted earlier than the Nil tubers. In fact, the NP tubers had sprouted even later:-

Table 10 : % of tubers sprouting at time of sampling for inhibitor assay

Treatment	NPK	NP	K	Nil
% sprouting	45	5	15	8

It was felt at this stage, therefore, that differences in the levels of the Inhibitor β complex as measured by the wheat coleoptile straight growth assay only partly explained the observed differences in the time of appearance of sprouts.

One possible explanation was that the criticisms of the assay by Burton (1963) were justified, and so it was decided to develop an assay relevant to the present study.

Tuber dormancy assay :

What was needed was a technique involving the use of dormant potato tissue. Previous attempts to achieve this have generally failed, for a variety of reasons. Thus, Buch and Smith (1959) were able to soak eye plugs, cut from non-dormant tubers in the acid inhibitor and emonstrate its continued activity by re-extraction after the plugs had sprouted. This simply shows, however, that the acid inhibitors will not alone produce dormancy in non-dormant tissue, and other workers have delayed sprout growth in dormant plugs by the continued application of pure abscisic acid (Blumenthal-Goldschmidt and

Rappaport, 1965). Such a technique was not feasible here where only crude extracts of the inhibitors were available.

A more realistic technique would be to use whole tubers which were in contact with a very dilute solution of the extract being assayed for as long as possible. To do this, the technique of Goodwin (1966) for breaking dormancy was modified.

Whole mature non-sprouting tubers each weighing 50 - 90 g were used as assay material. Bulk extracts were made of the peel from two samples of 25 kg of freshly collected mature tubers, and the paper chromatograms divided into 10 Rf strips, as for a wheat bioassay. Thirteen unreplicated treatments were used, comprising each of the 10 Rf strips, a combination of strips of Rf 0.2, 0.4 and 0.7, gibberellic acid, and a blank strip control. The strips were placed in polythene bags and to each bag was added 100 ml distilled water and nine potato tubers, except for the treatment with gibberellic acid in which a 1 p.p.m. solution was used instead of water. The bags were agitated daily to ensure an even distribution of the extracts over the tubers.

After 8 days in the dark at 13°C, many of the tubers had developed "soft rot" and were discarded but none were lost from the sample treated with the chromatogram strip presumed to contain the inhibitor complex. The remaining tubers were placed in trays in the dark, and records made of date of sprouting, sprout length and final sprout weight. These are presented in Table 11 and Fig. 8.

FIG. 8

Fig. 8 : Tuber Dormancy Assay

'X' = Mixture of Rf 0.2, 0.4 and 0.7

'GA' = Gibberellic acid, 1 p.p.m.

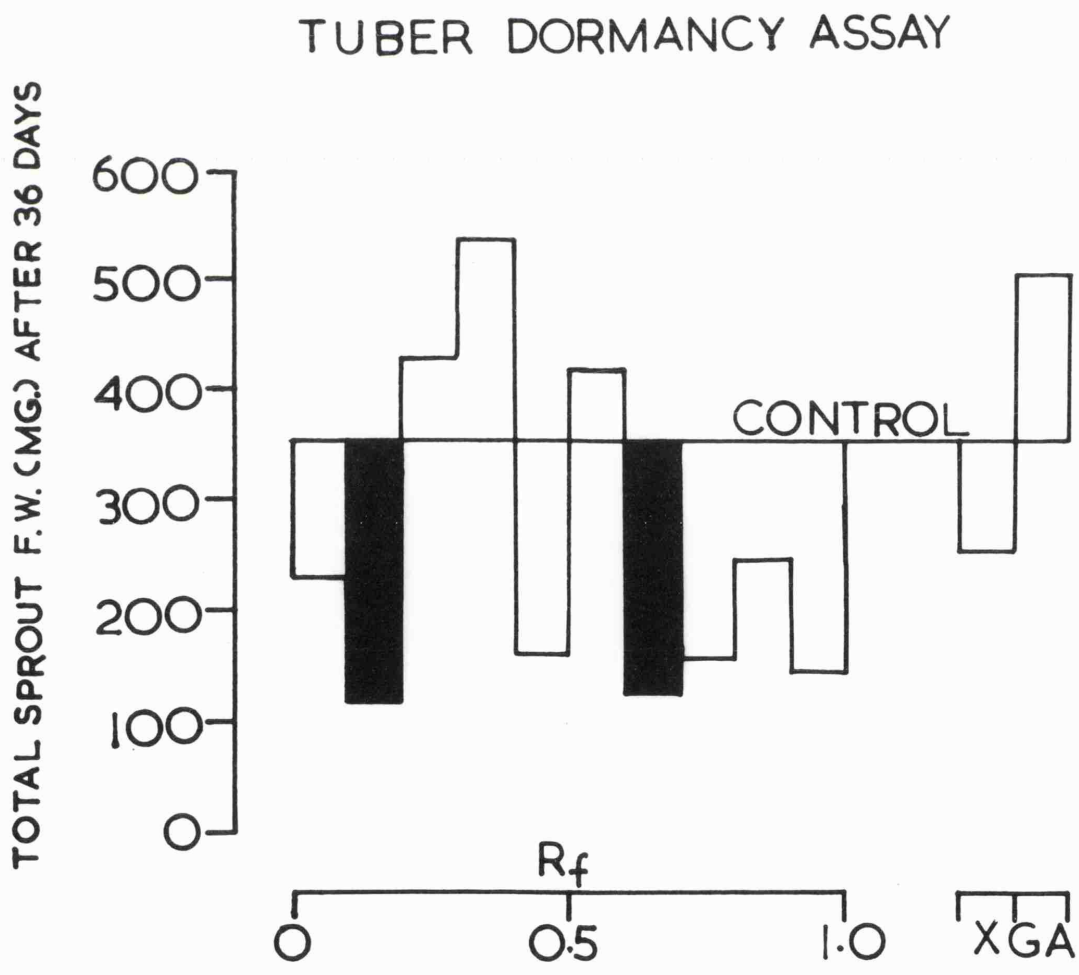

TUBER DORMANCY ASSAY
TOTAL SPROUT F.W. (MG.) AFTER 36 DAYS
600
500
400
300
200
100
0
CONTROL
Rf
0
0·5
1·0
XGA

Table II : Effect of tuber extracts and gibberellic acid on the sprout growth of whole tubers

Treatment	Healthy tubers	Total eye number	% sprouting at 21 days	Total sprout length (mm) at 29	33	35 days	Total sprout weight per tuber at 36 days (mg) fresh	dry
Rf 0.1	8	63	27	16	23	25	229	30
0.2	5	58	5	10	16	18	117	16
0.3	5	36	28	31	39	40	429	52
0.4	3	30	33	33	57	58	538	61
0.5	5	46	41	15	21	22	159	21
0.6	6	49	49	44	56	59	420	50
0.7	9	68	6	8	15	17	125	19
0.8	7	75	52	17	22	23	158	23
0.9	4	29	41	21	25	26	249	32
1.0	6	58	47	14	18	20	143	22
Water Control	4	33	73	28	34	35	353	43
Rf 0.2+0.4+0.7	4	33	24	17	22	24	252	34
GA, 1 p.p.m.	1	10	90	139	162	164	512	64

These results confirm the previous and mostly circumstantial evidence that the Inhibitor β complex does delay the appearance of sprouts in whole tubers. Of the other four zones of inhibition, detected at Rf 0.2, 0.5, 0.8 and 1.0, the inhibitor at Rf 0.2 was the only one, other than the complex, which markedly reduced the proportion of eyes sprouting in addition to final sprout weight. From this it was reasoned that the other inhibitors were retarding sprout growth rather than delaying sprout appearance. The slight stimulation in sprout growth after treatment with Rf 0.4 and 0.6 was probably due respectively to auxins and gibberellins, which normally run at these positions in this solvent system.

Because of the variability of the material and the losses due to rotting, the statistical analysis was limited on the advice of J.T. Wood (Statistician) to those treatments directly relevant to the thesis. These were considered to be treatments with natural gibberellins, and treatments with inhibitors which delayed the appearance of sprouts as well as subsequent growth when compared with the blank control i.e. treatment with Rf 0.6, and 0.2 and 0.7. The analysis of variance is shown in Table 12.

As the difference in sprout weight between the control tubers and those treated with Rf 0.2 and 0.7 was almost exactly equal to the l.s.d. for significance with P=0.05, it was concluded that, in addition to the β inhibitors, the inhibitors present around Rf 0.2 contributed to the maintenance of dormancy. On re-examining the results of the wheat bioassays, it appeared that differences in the

Table 12 : Effect of potato tuber extracts on total sprout dry weight (mg) per tuber - see text

	Treatment Rf			
	Control	0.2	0.6	0.7
	55.4 mg	10.0	26.8	3.9
	7.2	33.5	53.9	5.1
	64.0	15.6	100.9	33.0
	46.7	13.3	66.4	26.5
		6.3	25.6	36.6
			28.3	17.2
				11.8
				16.2
				17.9
Σ	173.3	78.7	301.9	168.2
n	4	5	6	9
$\bar{x}$	43.3	15.7	50.3	18.7

S.E. of mean = $\pm$ 19.8

L.S.D. (P=0.05) C and 0.2 = 27.7

C and 0.6 = 26.7

C and 0.7 = 24.8

activity of this zone might be related to previous nutrient treatment of the tubers. This area of the chromatogram was therefore examined in more detail.

c) Ultra-violet fluorescence of inhibitors:

It is well established that certain groups of compounds fluoresce in characteristic ways under ultra-violet light, and this can be used as an analytical technique (Gänshirt, in Stahl 1965). The paper chromatograms were therefore examined under an "Ultrascan" u/v lamp. A typical set of results is presented diagramatically in Fig. 9a, and the time sequence of the changes presented in Fig. 9b. It can be seen that there were several bands of fluorescence, including the area of Rf 0.2. It was also apparent that there were differences in the intensity of this fluorescence which was related to nutrient treatment.

This fluorescence was characterized using an Aminco-Bowman spectrophotofluorimeter. Normally the substance to be characterized is prepared in solution in a pure form and the u/v activation and emission spectro determined from this. In this instance, the paper chromatograms were used direct, by cutting out strips from around Rf 0.2 which would fit into the glass cells normally filled with solution. This enabled clear spectra to be obtained without the additional labour of extra purification of the crude extract. The activation and emission spectra for two zones of fluorescence (Fig. 10 a and b) are around Rf 0.2 the other at about Rf 0.3, indicate that single compounds were being measured.

FIG. 9

Fig. 9 : Effect of previous nutrient treatment on the fluorescence of tuber extracts - 1967 seed crop

A) Differences in tubers 6 weeks after harvest

Three fluorescent zones are illustrated, at Rf 0.0 (starting line), and around Rf's 0.2 and 0.3

B) Differences in tuber initials, and tubers, on 6 sampling dates

The fluctuations in the fluorescent zone around Rf 0.2 are illustrated for extracts from:-

1 = Tuber initials

2 = Growing tubers

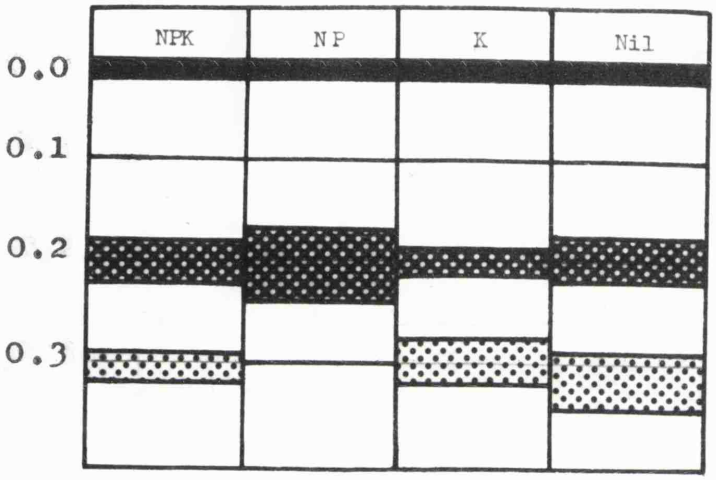
3 = Tuber 6 weeks after harvest

4 = " 10 " " "

5 = " 19 " " "

6 = Non-sprouting tubers from samples beginning to sprout.

A)



B)

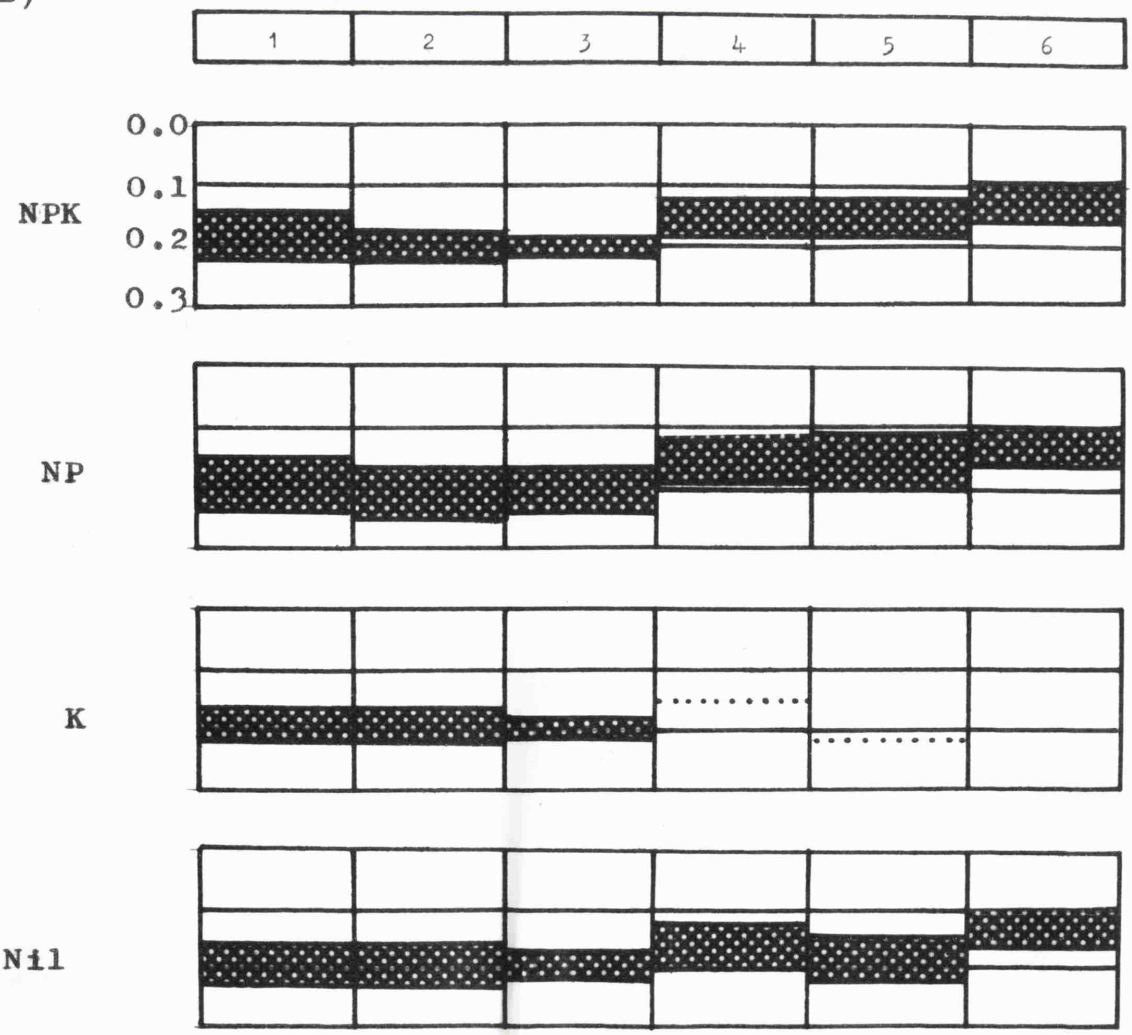


FIG. 10

Fig. 10 : Ultra-violet activation and emission spectra

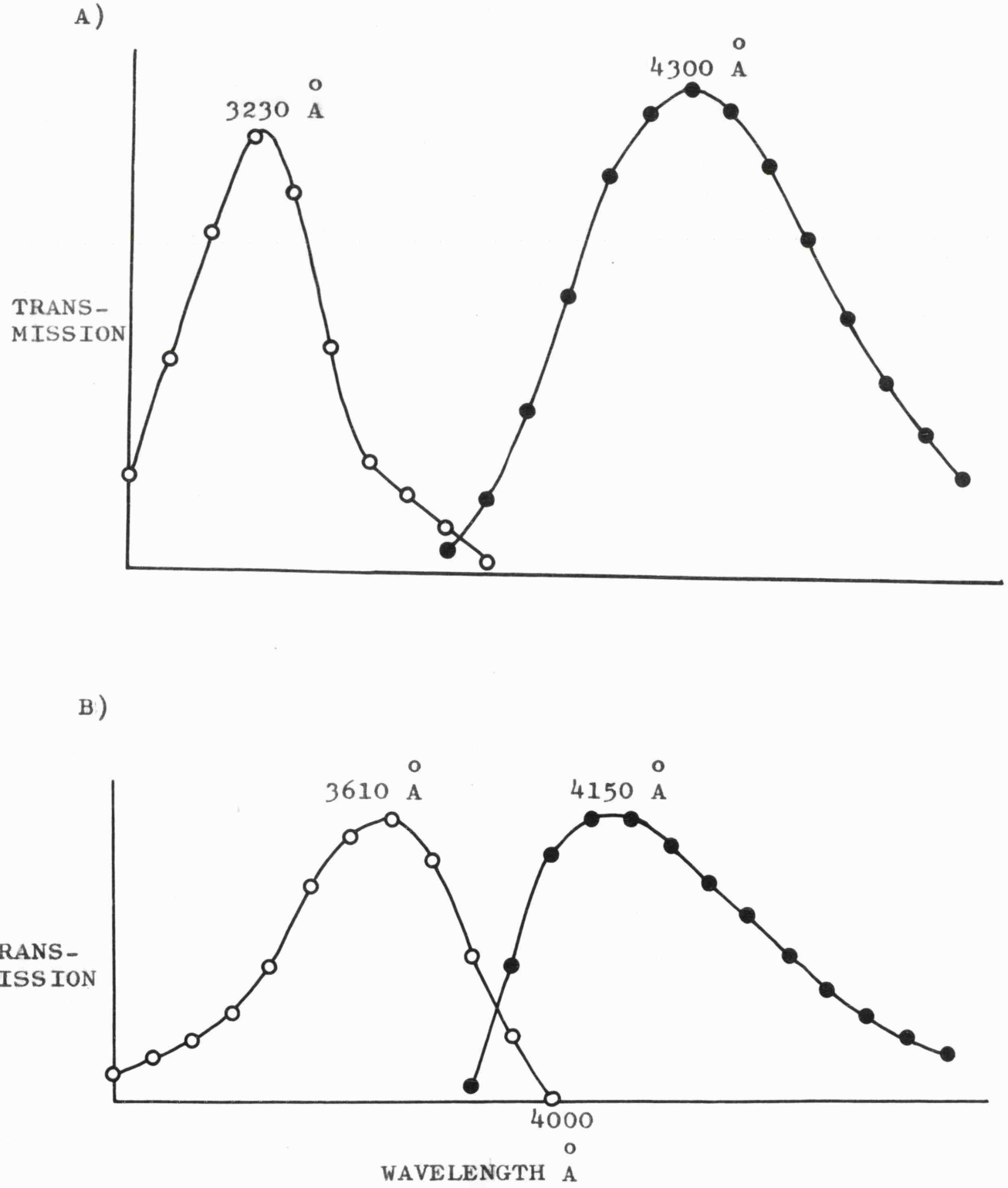
A) Fluorescent zone around Rf 0.2

B) " " " " 0.3

White circles = Activation spectra

Black circles = Emission spectra

The peaks are quoted for each spectrum


A)
4300 A
3230 A
TRANS-
MISSION
B)
3610 A
4150 A
TRANS-
MISSION
4000
WAVELENGTH A

Comparisons were then made between the intensity of fluorescence at Rf 0.2 at a series of sampling dates. This was done by measuring the intensity of fluorescence at the emission wavelength peak, with the wavelength of the stimulating u/v source set for maximum fluorescence. The final values are correlated with sprouting data (Fig. 11). Significant features of these observations are:-

1) the marked rise in fluorescence in tubers from treatment NP from soon after harvest until after the beginning of sprouting.

2) the consistently lower levels of fluorescence in tubers from treatments NPK and K.

3) the earlier drop in the level of fluorescence in tubers from treatment Nil.

These can be respectively correlated with:-

1) the longer dormancy and slow rate of appearance of sprouts on tubers from treatment Np.

2) the short dormancy of tubers from treatments NPK and K compared with the other two sets of tubers.

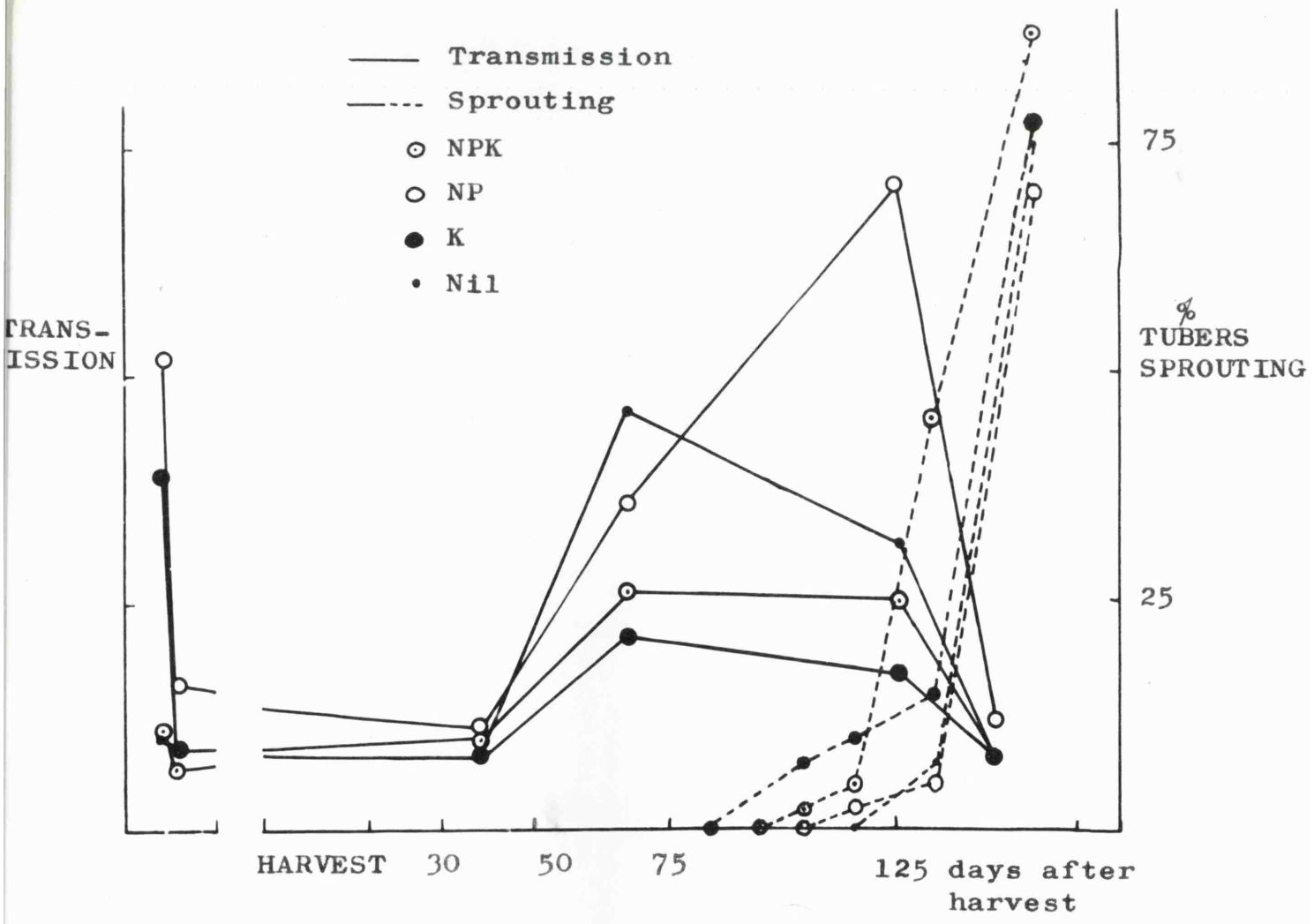
3) the high rate of appearance of sprouts in tubers from treatment Nil.

d) Ultra-violet absorption of paper chromatography eluates:

The next step was to attempt to identify the fluorescent compound. It seemed from the literature that the fluorescence around Rf 0.3 could have been caused by the coumarin, scopeletin. This was noted by Housley and Taylor (1958) in extracts of tuber peel, and also by Sargent and Skoog (1961) in extracts of media on which tobacco callus

FIG. 11

Fig. 11 : Effect of previous nutrient treatment on the fluorescence of tuber extracts at Rf 0.2, related to time of appearance of sprouts


Transmission
Sprouting
NPK
NP
K
Nil
TRANS-
ISSION
%
TUBERS
SPROUTING
75
25
HARVEST
30
50
75
125 days after
harvest

had been cultured. If this were so, then the fluorescence around Rf 0.2 could have been caused by a related β glycoside, as one such compound, scopoletin gentiobioside was demonstrated at a similar Rf in the same solvent system by Sargent and Skoog, 1961. In a previous publication (Sargent and Skoog, 1960) these authors postulated an equilibrium reaction between these two compounds, with high levels of scopoletin (and so presumably low levels of the glycoside) favoured by high levels of auxins. Increases in auxin levels have been produced by high K treatments in seedlings of Solanum nigrum which is closely related to the potato (Wahkloo, 1965).

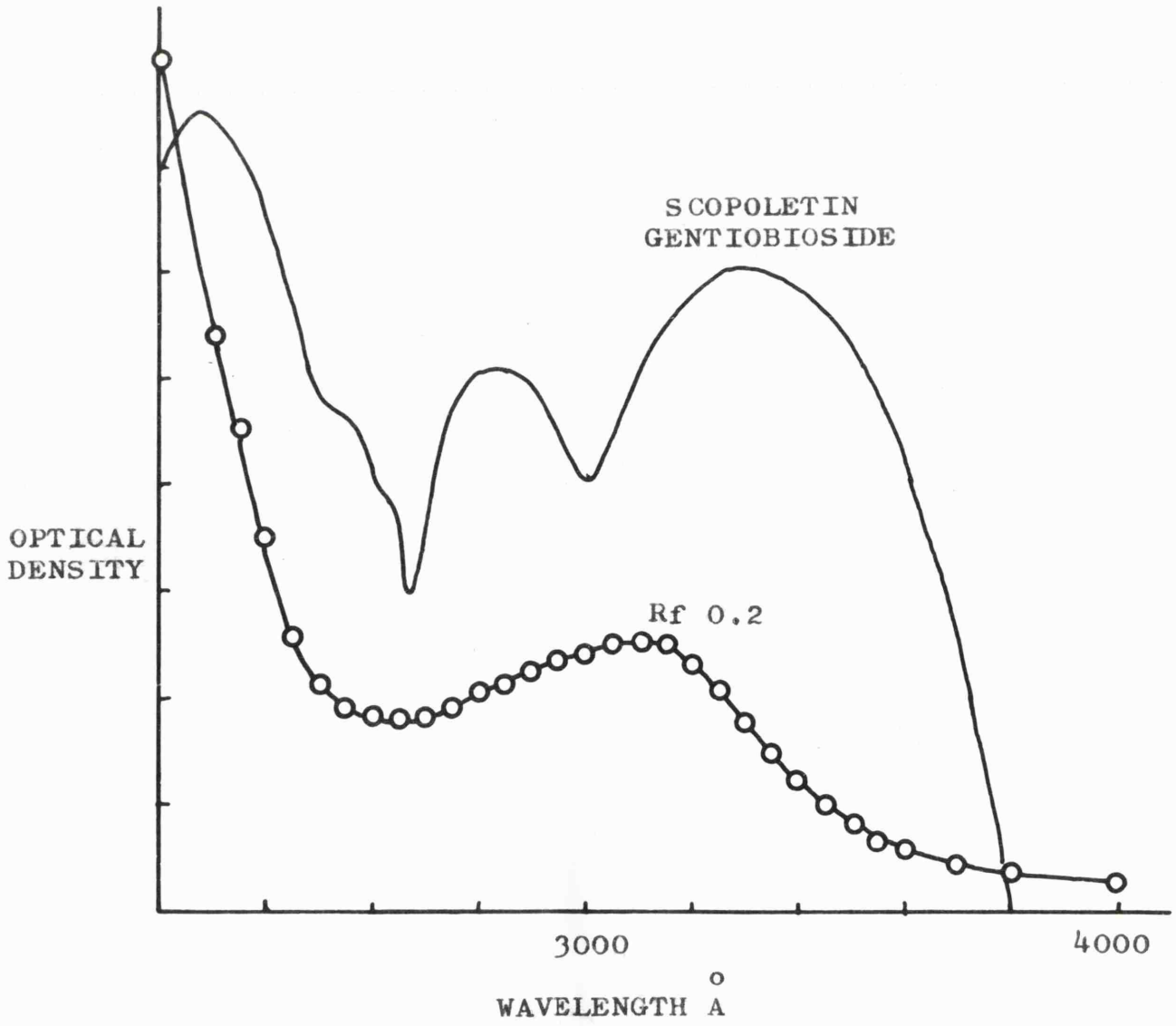
As u/v absorption spectra had been published for both scopoletin and the β glycoside, it was decided to elute the fluorescent section of the chromatogram and compare the spectrum so obtained with the published ones.

Accordingly, two strips cut from the zone of fluorescence at Rf 0.2 were agitated in a cell containing 80% ethanol, and the u/v absorption spectrum of the eluate obtained between 220 and 400 mu using a Unicam SP 800 spectrophotometer. Alcohol in which a blank strip had been agitated was used as blank. The spectrum is shown in Fig. 12. This is not characteristic of any particular compound and more likely represents the combined spectra of a mixture of u/v absorbing substances all occurring at this Rf. Thus, at this stage of purification, the u/v absorbing properties of the substances in the fluorescent zone of inhibition did not contribute to the indentification of the fluorescent compound.

FIG. 12

Fig. 12 : Ultra-violet absorption spectra for eluate of fluorescent zone at Rf 0.2, and scopoletin gentiobioside

The spectrum for scopoletin gentiobioside is that published by Sargent and Skoog (1961)


SCOPOLETIN
GENTIOBIOSIDE
Rf 0.2
OPTICAL
DENSITY
3000
4000
WAVELENGTH A°

The matter could be resolved by comparing the fluorescence of scopoletin and its β glycosides with the unknowns. A sample of scopoletin was eventually obtained, but the u/v spectrophotofluorimeter was not then available. However, a fluorescent band was detected around Rf 0.3 when a portion of this sample was partitioned in the solvent system described in the previous section, which suggests that the compounds could be scopoletin and a related β glycoside.

3 iv) Discussion

It was concluded that the previous nutrient treatment could affect not only the eye number for a given weight of tuber but also the percentage of those eyes sprouting and the time at which the sprouts appeared. These differences could be correlated with the levels of acid inhibitors of the β complex for balanced nutrient treatments, although when differences were produced by imbalanced treatments there was a better correlation with the levels of fluorescence from a zone of inhibition which appeared to be related to the rate of appearance of sprouts. It was apparent that these imbalanced treatments produced trends in the percentage of eyes which sprouted which counteracted the trends in number of eyes per tuber. Thus the high K treatments produced tubers with fewer eyes but with a greater number of those eyes sprouting than for low K treatments. This might have been due to differences in the concentration of correlative inhibitor, isolated by Goodwin (1967) related to previous nutrient treatment as was the fluorescent inhibitor, but in practical terms this suggested that the use of eye number per seed tuber for predicting stem number might be complicated unless the tubers were produced by plant grown under balanced nutrient treatments.

The next step therefore was to study the effects of previous treatment on sprout and stem growth, with emphasis on stem growth.

4

SPROUT GROWTH IN STORE

4 : Sprout growth in store

4 i) Introduction

The object of these experiments was to determine whether there were relative differences in the number and development of sprouts on whole tubers that could be related to the previous nutrient treatment. If there were such differences, then it might be possible to predict relative differences in stem number and field performance.

It was decided to study first the sprout weight and number per tuber. The only directly relevant previous work found, after the initial experiments had been carried out, was that of Alten et al (1960). They recorded the total sprout length per tuber (after six months in store at three different temperatures) for tubers produced under four different fertilizer treatments. Changing the storage temperature altered the relationship between previous nutrient treatment and sprout length as well as the absolute length of the sprouts. No details were given of tuber size or sprout number.

4 ii) Effect of K

The nutrient treatments applied in 1966 provided sources of tubers with a wide range of mineral levels. One set of sources had been chosen to study the effects of previous K treatment on time of appearance of sprouts (Section 3) and performance in the field (Section 5). Another set of sources was therefore chosen to provide tubers with a similar range of mineral levels, so that sprout weight and number on tubers in store could be measured when the tubers planted in the field had just emerged. Accordingly, two sets of 20 tubers closely matched for weight were chosen from each source, and left in store until all the tubers in the field experiment had just produced visible stems. The sprouts on each tuber were then counted, weighed and the tubers analysed for NPK. The means of these sets of data are presented in Table 13. It is clear that there were differences in the total sprout weight per tuber, although there was no clear-cut relationship with tuber mineral levels. However, there seemed to be an optimum level for tuber K, with sprout number and sprout weight depressed at the highest K levels. This supported a similar conclusion drawn from the studies on the time of appearance of the sprouts. There were also fairly large differences in the percentage of eyes sprouting at the higher tuber weight, although the difficulty in assessing the eye numbers has already been stressed.

In addition it was possible to roughly weight match three sets

Table 13 : Effect of previous nutrient treatment on sprout weight and number after 26 weeks in store - 1966 seed crop

a) Tubers 20 - 30 g	K_1P_4	K_2P_2	DK_2P_1	K_4P_1
Mean tuber weight (g)	25.6	25.1	25.3	25.4
Total sprout weight/tuber (g)	0.48	0.38	0.55	0.32
Total sprout number/tuber	3.0	2.7	2.7	2.7
Mean sprout weight	0.16	0.14	0.20	0.12
Eye number/tuber	7.8	6.7	6.6	7.4
% eyes sprouting	38.5	40.3	41.0	36.5
N (% D.M.)	1.63	1.21	1.35	1.33
P	0.32	0.26	0.30	0.23
K	1.23	2.08	2.43	2.53
K/N	0.75	1.72	1.80	1.90
b) Tubers 50 - 70 g				
Mean tuber weight (g)	56.1	58.0	59.2	57.1
Total sprout weight/tuber (g)	0.92	0.94	1.01	0.67
Total sprout number/tuber	4.6	5.1	4.4	3.8
Mean sprout weight	0.20	0.18	0.23	0.18
Eye number/tuber	8.2	6.9	7.1	7.5
% eyes sprouting	56.2	73.0	62.0	50.7
N (% D.M.)	1.45	1.04	1.27	1.17
P	0.32	0.25	0.25	0.25
K	1.34	1.97	2.44	2.47
K/N	0.92	1.89	1.92	2.11

Details are given of seed crop treatments in Appendix 6.

of tubers from the last four tubers remaining from four of the five seed sources used in the field experiment, and to weigh the sprouts on these also. As the samples were so small, no conclusions were drawn but the results are included for the sake of completeness.

Table 13 b : Effect of previous nutrient treatment on sprout weight and number after 26 weeks in store - field experiment sources

Mean tuber weight	41.9	40.0	37.9	39.2
Total sprout weight/tuber	1.92	2.19	2.16	2.18
Sprout number/tuber	2.3	3.0	3.8	3.8
Mean sprout weight/tuber	0.60	0.56	0.53	0.57
N % D.M.	1.10	1.09	1.16	1.38
P	0.29	0.26	0.27	0.35
K	1.96	2.08	2.31	2.28

4 iii) Effect of balanced and imbalanced nutrient treatments

The preliminary studies with the 1966 seed crop had shown that there were differences in sprout weight and number on tubers with different mineral levels, and that in general the differences followed the same trend as for differences in the numbers of tubers with sprouts visible.

The time sequence of these differences was followed in the 1967 seed crop, and it was therefore possible to relate differences in sprout weight to a specific physiological stage in the sprouting and thence estimate the growth period for the sprouts. For this, the time to 50% sprouting was chosen, because the plot of % tubers with visible sprouts against time, shown in the previous section, (Fig. 5) has the characteristics of a seed germination curve, for which the 50% point is the most relevant.

The closely weight-matched tubers used in determining the time of appearance of sprouts were desprouted after 27 weeks in store, and total sprout weight and number per tuber determined. In addition, the largest sprout was weighed. It was only possible to match tubers weighing up to 60 g for all treatments and therefore detailed studies were limited to this weight range. A summary of the data is given in Table 14, details in Appendix 5.

Table 14 : Effect of previous nutrient treatment on sprout growth - 1967 seed crop

	Treatment			
	NPK	NP	K	Nil
Total sprout weight/tuber (mg)	238.4	140.3	160.6	146.5
Total sprout number/tuber	2.90	2.90	3.15	3.30
Mean sprout weight per tuber (mg)	82	49	51	44
Days to 50% sprouting	124	140	130	133
Sprout growth period	65	49	59	56
N % D.M.	1.52	1.68	1.05	1.23
P	0.23	0.25	0.29	0.30
K	1.88	1.24	2.02	1.79

Thus the heaviest sprouts were associated with the longest sprout growth period, produced by treatment NPK. However, the smallest sprouts were on tubers from treatment Nil, the shortest growth period being that for tubers from treatment NP. As tubers from treatment Nil also had the largest stem number, one possible explanation was that there had been competition for minerals, as reported by Morris (1966). Sprout growth has been related to tuber N and more specifically proline by Alten et al (1960), and the Nil tubers had the second lowest N levels. The similar sprout weights at this time for tubers from treatments NP and K can be explained on the basis of the high N levels compensating for the short growth period in treatment NP and the initial advantage of a long growth period being lost due to low N in treatment K.

Another possibility was that there were different degrees of apical dominance. Goodwin (1967) noted that the relative sizes of the apical sprout and the other sprouts was a critical factor in determining whether this phenomenon occurred. This was checked by calculating the ratio of the largest sprout weight to the mean of the other sprout weights. This is shown in Table 15.

Table 15 : Effect of previous nutrient treatment on apical dominance - 1967 seed crop

	Treatment			
	NPK	NP	K	Nil
Largest sprout weight = A *	122.4	79.4	95.3	83.6
Mean of remaining sprouts = B	45.4	29.6	29.4	25.0
A/B	2.70	2.68	3.24	3.34

* Means for 40 matched tubers as in Table 14

Thus there was a greater degree of apical dominance on the two sets of tubers with low N levels (from treatments K and Nil) than on the tubers with high N (from treatments NPK and Nil).

The interaction of storage temperature and previous nutrient treatment on total sprout length per tuber reported by Alten et al (loc. cit) has already been noted. To check this, a further sample from each treatment was stored in a heated shed for three months. Sprouts had appeared on these tubers about two months before there were signs of sprouting on the tubers in the main store. Once it was judged that all the tubers had sprouted, they were transferred to the main stofe and desprouted at the same time as for the main

experiment.

Table 16 : Effect of lengthened sprout growth period on differences in apical dominance due to previous nutrient treatment

	Treatment			
	NPK	NP	K	Nil
Total sprout weight/tuber (mg) *	870	901	731	805
Total sprout no/tuber	1.8	2.0	1.9	1.8
Overall mean sprout weight/tuber (mg)	483	450	359	340
Largest sprout weight (mg) = A	614	584	499	612
Mean of remaining sprouts = B	320	317	204	241
Ratio A/B	1.92	1.84	2.45	2.54

* Means of 27 matched tubers weighing up to 60 g

This treatment resulted in a reduction in sprout number from around 3 to about 2 per tuber, and an increase in sprout weight from around 200 to about 800 mg per tuber. There was also little difference between sprout weight on tubers from treatments NPK and NP, which now formed a pair distinct from the tubers from treatments K and Nil. It was therefore concluded that the longer the sprout growth period the more differences in sprout growth could be related to tuber N.

All these comparisons were made on tubers weighing up to 60 g since it was not possible to match tubers for all treatments above this weight. It was possible, however, to match tubers from treatments NPK? NP and K up to a weight of 130 g and treatments NPK and NP up to 220 g. The relevant means are presented in the following table, the full results in Appendix 5.

Table 17 : Effect of increase in tuber weight on differences in total sprout growth due to previous nutrient treatment

		Treatment			
		NPK	NP	K	Nil
Mean Tuber Wt.	Mean total				
14	Spr. Wt.	109.0	51.1	82.0	58.7
	Spr. No.	2.2	2.0	2.5	2.3
55	Spr. Wt.	355.9	245.6	243.9	250.8
	Spr. No.	3.7	4.2	4.6	4.7
77	Spr. Wt.	370.8	393.6	318.5	
	Spr. No.	4.1	5.4	5.8	
153	Spr. Wt.	486.4	681.1		
	Spr. No.	5.8	7.0		

The most striking feature of these results is the relative change between sprout growth on tubers from treatments NPK and NP as tuber weight increases. Thus for tubers of average weight 14 g, the sprout weight for tubers from treatment NPK is about twice that for treatment NP, whilst for tubers weighing 153 g the sprout weight for tubers from treatment NP is about one and a half times that from treatment NPK. This is largely due to the greater sprout number for treatment NP. There was a slight increase in sprout number for tubers from treatment K which confirmed the earlier conclusion that a greater proportion of the eyes sprouted on tubers with high K or possibly K/N.

The significance of these differences was tested statistically using the data from the tubers from the NPK treatment as standard, and calculating the 't' value for the sums of squares of the differences These values are given in Tables 18a and b.

4 iv) Discussion

The tables clearly demonstrate that differences in sprout weight between treatments were most pronounced for small tubers whilst those for sprout number were greater for large tubers. It was also apparent that the rate of sprout rate after the sprouts had appeared could differ and that the longer the sprouts grew the more differences were related to N. As the time of appearance of sprouts had been related to K, this confirms the value of distinguishing between the time of appearance of sprouts and subsequent sprout growth emphasised in Section 3 i.

Table 18a : The effect of previous nutrient treatment on sprout growth total sprout weight per tuber on matched tubers of increasing weight compared statistically using treatment NPK as standard

Treatments NPK and NP

Tuber No.	Tubers weighing	't' value	't' (P=0.05)
20	2 - 26 g	2.65 *	2.09
20	26 - 58	2.15 *	2.09
20	58 - 102	0.23	2.09
20	102 - 220	1.71	2.09

Treatments NPK and K

Tuber No.	Tubers weighing	't' value	't' (P=0.05)
20	2 - 26	0.78	2.09
20	26 - 58	1.62	2.09
26	58 - 130	0.02	2.06

Treatments NPK and Nil

Tuber No.	Tubers weighing	't' value	't' (P=0.05)
20	2 - 26	2.44 *	2.09
30	26 - 72	0.86	2.05

Table 18b : The effect of previous nutrient treatment on sprout growth - sprout number per tuber on matched tubers of increasing weight compared using treatment NPK as standard

Treatments NPK and NP

Tuber No.	Tubers weighing	't' value	't' (P=0.05)
20	2 - 26 g	0.53	2.09
20	26 - 58	0.86	2.09
20	58 - 102	2.77 *	2.09
20	102 - 220	2.12 *	2.09

Treatments NPK and K

20	2 - 26	0.74	2.09
20	26 - 58	1.23	2.09
26	58 - 130	3.89 *	2.06

Treatments NPK and Nil

20	2 - 26	0.14	2.09
30	26 - 72	2.92 *	2.05

5

TUBER PERFORMANCE IN THE FIELD

5 : Tuber performance in the field

5 i) Introduction

The main object of all the previous experiments had been to look for differences in the performance of the seed tuber due to previous nutrient treatment which might be expected to produce yield differences when the seed tubers were grown in the field. The results of these experiments indicated that any net difference in yield would be the result of the counteracting effects of K and N. However, Ramsay (1917) showed that tuber K is not exported to the growing plant, whilst Headford (1961) showed that in nutrient solution culture the seed tuber had a sparing action on the uptake of N through the roots. It might therefore be anticipated that the longer growth proceeded, the greater the effect of N should be.

It was pointed out in the introduction that the few previous workers in this field had not standardized the seed tuber in any way. Such standardization therefore forms an important part of the study. Tuber weight, stem number, and tuber nutrient levels were used as bases for the standardization.

5 ii) Studies in 1967

The tubers from the 1966 seed crop used in establishing the differences in the time of sprouting were used for the field experiment. The five treatments were coded A to E in order of ascending tuber K. As the supply of material was limited, it was decided to plant as many tubers as possible from each source, harvest each plant individually and then combine the individual results when making specific comparisons.

a) Methods

120 tubers were carefully chosen from each source in such a way that some tubers from all sources could be matched, if required, for a) weight only b) eye number only c) weight and eye number. Such a flexible design, which was considered essential in a study of this sort, complicated the statistical planning. It was eventually decided to lay out five blocks to account for any systematic errors due to variations in ploughing as well as soil variation, assigning 24 tubers to each block at random. Since the matchings envisaged unavoidably involved using the same seed tuber several times, the randomization could only be done using one tuber variate and for this tuber eye number was chosen. This effectively limited the use of the blocks to comparisons based on tuber eye number.

A site was prepared for the experiment as in good commercial practice in a low yielding, medium loam soil, and a set of 12 ridges, each 24" apart, was drawn up in early April. The five blocks were

laid out across the line of the ridges, and the seed tuber individually planted at a 12" spacing within the row using a pot-holer.

b) Time of emergence

The seed tubers were planted on April 5, and the plants began to emerge on April 26. Daily emergence counts were made, details of which are given in Appendix 4.

It was considered that the time of appearance of sprouts on the unplanted seed tubers might affect emergence, and to detect differences in emergence due to this, the earliest emergence data ought to be used because the further away from the time of planting the greater the chance of other factors affecting stem growth. It was suggested in the introduction that differences in stem number and in the supply of reserves from the seed tuber were also factors which could be altered by the previous nutrient treatment. Differences in emergence due to differences in these factors might be expected to become greater with time.

Comparisons were made 25 and 30 days after planting (Table 19a) and at the 5, 50 and 75% emergence stage (Table 19b).

When tubers matched for weight are compared, there is a fairly good correlation between early field emergence and the time of appearance of sprouts on the seed tubers in store. Thus the numbers of plants which had appeared rose to a maximum for tubers from treatment D with a slight drop from treatment E. This is illustrated in Fig. 13.

FIG. 13

Fig. 13 : Relationship between differences in the proportion of eyes sprouting in store, and stems emerged in the field - 1966 seed crop grown on in 1967

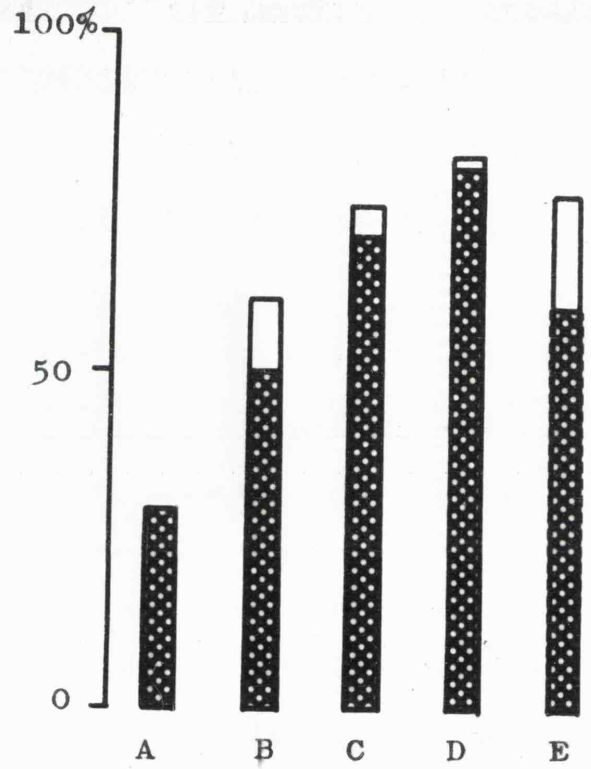
A) 10 seed tubers matched for weight and eye number

B) 50 small seed tubers matched for weight

Stippled area = % stems emerged 25 days after planting

Stippled + white area = % eyes sprouting on seed tubers 21 weeks after harvest

A)



B)

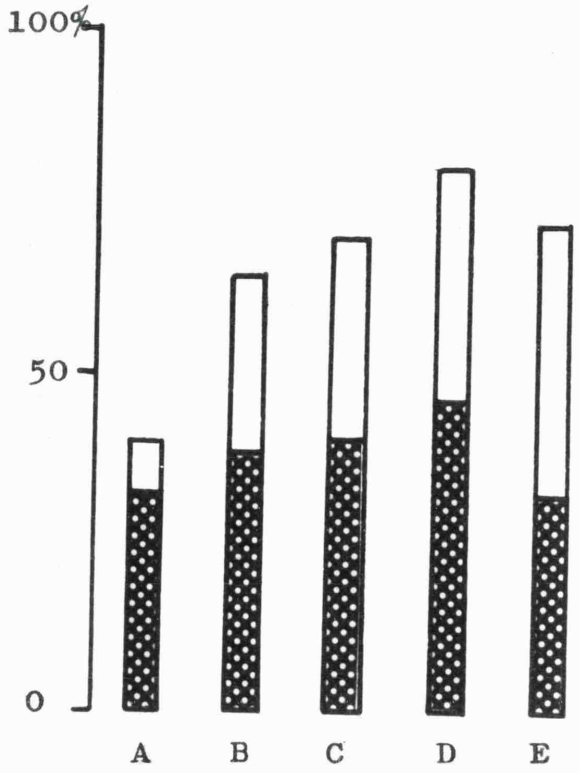


Table 19a : Effect of previous nutrient treatment on percentage of total plant number emerged

25 days after planting

	Treatment				
	A	B	C	D	E
Complete sample	33	48	43	60	33
90 weight matched tubers		50	50	61	33
50 small matched tubers	32	38	40	46	32
40 large matched tubers		67	60	80	35
10 eye no. & weight matched	30	50	70	80	60

30 days after planting

	Treatment				
	A	B	C	D	E
Complete samples	76.7	81.7	72.5	85.0	73
90 matched tubers		87	73	88	78
50 small tubers	78	84	64	80	70
40 large tubers		90	85	98	87

Table 19b : Effect of previous nutrient treatment on days to emergence

	Treatment					Maximum difference (days)
	A	B	C	D	E	
		90 matched seed tubers				
Days to 5% emergence		22.7	22.5	22.2	22.8	0.6
25		23.6	23.6	23.2	24.5	1.3
50		25.0	25.1	24.5	25.8	1.3
75		28.1	30.2	27.1	29.8	2.7
Mean		26.4	27.2	27.0	28.0	1.6
		50 small matched seed tubers				
Days to 5% emergence	23.3	23.1	23.0	22.3	22.5	1.0
25	24.6	24.0	24.2	23.8	24.3	0.8
50	26.0	26.0	25.8	25.4	26.0	0.6
75	28.6	28.4	30.7	28.6	30.9	2.3
Mean	27.3	27.6	28.1	26.9	28.4	1.5
		40 large matched seed tubers				
Days to 5% emergence		22.4	22.3	22.1	23.3	1.2
25		23.3	23.3	22.9	24.6	1.7
50		24.0	24.0	23.7	25.8	2.1
75		25.8	28.0	24.8	29.0	3.2
Mean		25.6	26.2	24.7	27.4	2.7

However, as a greater proportion of the plants emerged, the plants from treatment C emerged more slowly. Thus at the 50% emergence point, there was little difference between treatments B and C, but at the 75% point treatment C was over two days behind. Because of this, the maximum difference between the treatments increased. (Fig. 14)

It should be mentioned here that 1°, 2° and 4°F of ground frost were recorded on the nights preceding days 27, 28 and 29 from planting respectively. All the emerged plants were covered with plant pots each night and there were no visual symptoms of damage, but the possibility that the set-back suffered by plants from treatment C was in part due to this incident was seriously considered at this stage. Toosey (1965) states "Growth at the beginning of the season is greatly affected by field environment. Sharp frosts can eliminate the lead in foliage development built up by pre-sprouted seed." He also reports that earlier tuber initiation due to low temperature at this critical stage has been shown to produce plants which are weak, small, have a poor growth rate and give reduced tuber yield. This point has been emphasized to demonstrate how easily any benefits of previous nutrient treatment might be lost. Certainly it would be difficult to protect a commercial field of emerging potatoes from frost. However, evidence will be presented in the next section which justify ignoring the possibility of sub-lethal frost damage and instead explaining the set-back in tubers from treatment C on a physiological basis. (p 82)

FIG. 14

Fig. 14 : Effect of previous nutrient treatment on the rate of emergence of plants in the following year - 1966 seed crop grown on in 1967

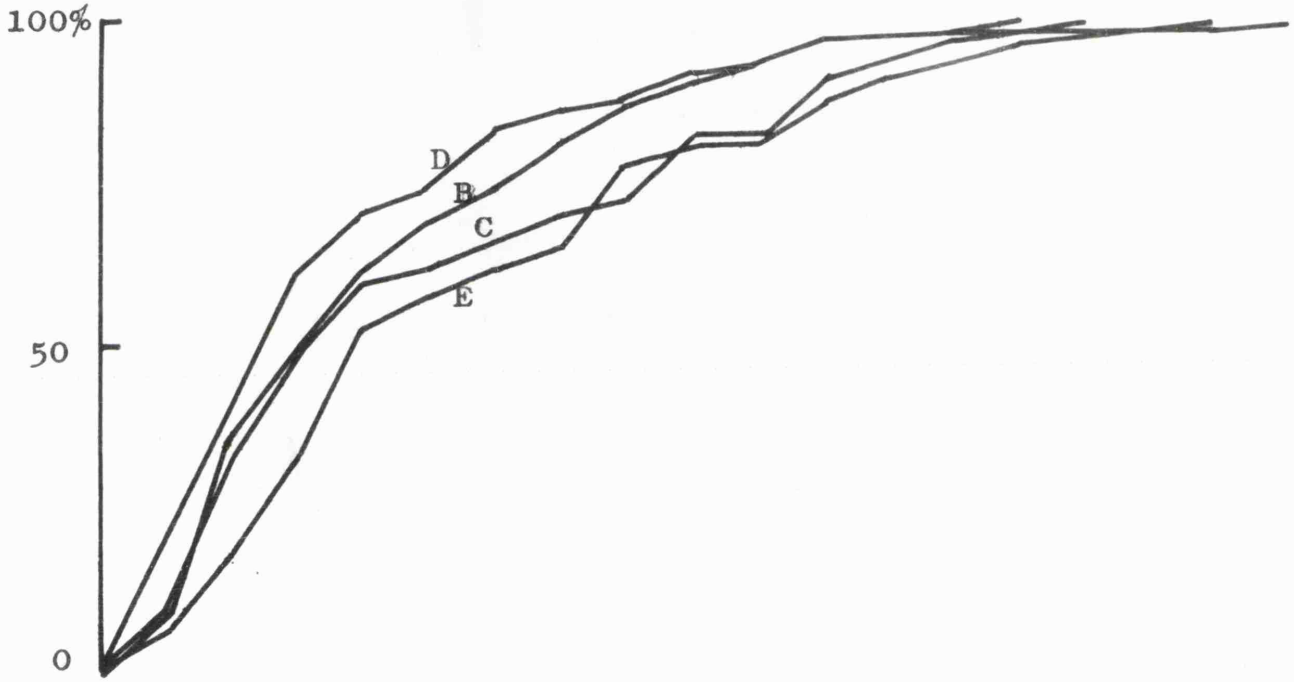
A) 90 seed tubers matched for weight

B) 40 large seed tubers matched for weight

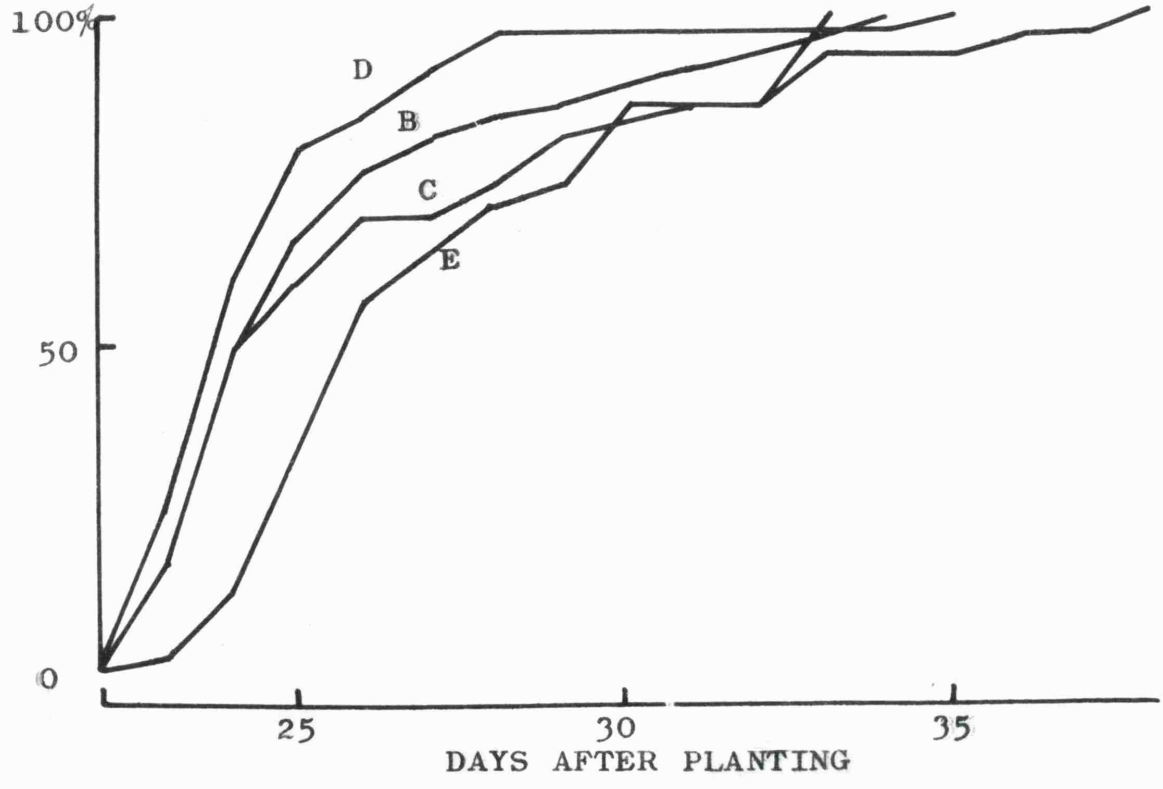
Letters on graph refer to previous nutrient treatment of seed crop - see text.

Treatment A is omitted as it was not possible to weight-match seed tubers weighing more than 50 g.

A



B



c) Tuber yield and stem number

The progress of tuber bulking was followed by trial diggings of spare guard plants, and all plants were lifted on June 19/20, seven weeks after 50% of all the plants had emerged.

Individual plants were put into labelled polythene bags as soon as they were harvested (Plate 1), and temporarily stored in a refrigerated store at 36°F until they could be dealt with.

Records were made of the total fresh weight of the haulm, the stem number, the tuber number, and individual tuber weights. As one original aim had been to relate eye number to stem number, the stem count was of main stems originating from an eye, and the very few aerial stolons, which gave the appearance of stems, were ignored.

The primary object of the experiment was to see if there were differences in tuber yield due to previous nutrient treatment, and so the total plant yields have been largely ignored. The complete data is presented in Appendix 4. Summaries of the relevant data are given in Tables 20 to 25. Each table will be discussed in turn.

Table 20 : Effect of previous nutrient treatment on tuber yield per hill (g) - means of 120 hills

	Treatment				
	A	B	C	D	E
Tuber yield per hill (g)	171.4	213.6	187.2	212.8	211.0
Mean seed tuber weight (g)	22.7	50.0	48.9	54.0	51.4
Tuber yield per 50 g seed	377.5	213.6	191.4	197.0	205.3

PLATE 2

Plate 2 : Harvesting procedure, 1967

Eight rows are visible, from the extreme left to the person on the right. Work has begun on the first block.

Row 1 : has been harvested, and the plants are laid out individually.

Row 2 : has been harvested and removed for analysis.

Row 3, 5 and 7 : are still to be harvested.

Row 4 and 6 : have been harvested and the individual plants are in polythene bags awaiting removal.

Row 8 : is being harvested.

It was noted in the introduction that seed tuber weight had not been standardized in the few studies previously carried out on this subject. This table illustrates that such an omission can obscure any effects sttributable to previous nutrient treatment. Although the mean seed tuber weight of the treatment C tubers was over twice that of the treatment A tubers, there was a difference of less than 10% in yield per hill. An effect of previous nutrient treatment in altering the size distribution of the seed tubers would be expected to be more important commercially where the standardization of seed size would be largely by bulk mechanised grading rather than individual hand grading but would not explain the high yielding performance of tubers from treatment A. The yields from the matched tubers, used in the previous experiments were therefore compared next.

Table 21 : Effect of previous nutrient treatment on tuber yield per hill (g) - seed matched for weight

	Treatment				
	A	B	C	D	E
Small seed (mean of 50)	205.9	175.8	159.0	186.1	186.1
Large seed (mean of 40)		290.2	265.0	277.6	275.8
Overall (mean of 90)		233.0	212.0	231.8	231.0

The most distinct feature of this comparison is the high yield of small tubers from treatment A, and the consistent lower yields of both small and large tubers from treatment C.

The object of the experiment had been to attempt to explain any differences in yield per hill in terms of quantitative or qualitative differences in the seed tuber reserves per stem. The observed differences in yield were therefore first related to stem number.

Table 22 : Effect of previous nutrient treatment on stem number per hill - seed matched for weight

	Treatment				
	A	B	C	D	E
Small seed	3.3	3.2	3.3	3.4	3.1
Large seed		5.3	6.2	5.7	5.4
Mean		4.3	4.8	4.6	4.3

It was unlikely that these small differences in stem number would explain differences in yield from the small seed tubers, as there was no difference in stem number for tubers from treatment A and C (the highest and lowest yielding treatments). For the large seed tubers, the highest stem number per hill for tubers from treatment C was associated with the lowest yield per hill. It was therefore possible that yield per hill might have been depressed by a supra-optimal stem number.

Such a depression might be due to either the low level of some nutrient (s) initially supplied by the seed tuber, or competition between the stems for the resources of the environment, or both. To estimate the magnitude of the effect of the seed tuber nutrients, comparisons were made between yield per hill for hills with the same

stem number. In this situation, the competition for the resources of the environment due to stem number would be the same, any residual differences presumably being caused at least in part by qualitative differences in the supply of seed tuber nutrients. Accordingly yields per hill were next compared for seed tubers matched for both weight and stem number.

Table 23 : Effect of previous nutrient treatment on tuber yield per hill (g) - seed matched for weight and stem number

	Treatment				
	A	B	C	D	E
Small seed (means of 27)	187.6	169.6	158.0	162.6	196.2

Thus there were indications of a considerable residual seed tuber effect. The statistical analysis is presented on pp.83-86

It was decided at this stage to test further the effects of the frosts on the results. It was noted earlier that one possible effect of low temperature on early haulm development was premature tuber initiation, with consequent stunted growth. It was reasoned that if the frosts had produced this effect then the result would have been a greater proportion of tuber in the total plant yield from the lowest yielding treatment. This was checked.

Table 24 : Tuber yield as a percentage of total yield

		Treatment				
		A	B	C	D	E
Small seed:	Tuber	205.9	175.8	159.0	186.1	186.1
	Total	352.0	310.6	280.4	324.2	319.2
	% tuber	58.5	56.6	56.7	57.4	58.3
Large seed:	Tuber		290.2	265.0	277.6	275.8
	Total		517.3	478.3	508.4	473.1
	% tuber		56.1	55.4	54.6	58.3
	Mean tuber		56.4	56.0	56.0	58.3

There were virtually no differences in these proportions, so it was concluded that the frosts were unlikely to have significantly affected the results.

Thus, the simpler hypothesis, that the residual qualitative seed tuber effect was due to differences in the supply of nutrients from the seed, was tested next. The chemical analyses of the seed tubers are presented below:

Table 25: Effect of previous nutrient treatment on the levels of tuber N, P and K.

	Treatment				
	A	B	C	D	E
N % D.M.	1.77 *	1.42	1.20	1.22	1.44
P	0.35	0.28	0.29	0.28	0.34
K	1.32	2.00	2.20	2.52	2.61

* Means of 10 analyses on tubers approximately matched for weight, weighing 3 - 130 g

Thus the lowest yielding treatment C had produced seed tubers with the lowest N levels, and the two highest yielding treatments, A and E, had produced seed tubers with the two highest N levels. There is probably a more direct relationship between certain N containing compounds and stem growth, rather than total N. For instance, Alten et al (1960) related the levels of tuber proline to sprout growth and to previous nutrient treatment. A better technique would be to take small samples from each seed tuber just prior to planting, analyse them separately for compounds such as proline, and relate the analyses to individual yields.

Having defined the differences in tuber yield per hill on a physiological basis, the next step was to test the differences statistically. After discussion with Mr. J.T. Wood (Statistician), it was decided to perform a 't' test on the sums of squares of the differences between the yields from the sets of matched seed tubers. The full data is presented in Appendix 4. As it had been concluded that tuber N was the most important factor studied in explaining yield differences due to previous nutrient treatment, treatment C was taken as a low N standard, and the yields from the seed tubers of the other treatments compared with it. This was done by comparing the five sets of 50 small seed tubers in two sets of 25, and the four sets of large seed tubers in two sets of 20. This was considered to be inherently more informative than an overall comparison of the complete sets of 90, since changes in the differences due to increases in seed tuber

weight would be revealed. The individual sets of comparisons could, however, be combined to give an overall 't' value if required.

The statistical comparisons are presented in Tables 26 and 27.

It can be seen from Table 26 that the differences in seed tuber N were significant (P=0.05) for only two comparisons, i.e. C and A, and C and E. This was probably partly because the sample number was low, and the ideal solution (sampling each tuber individually prior to planting) has already been mentioned. Such an approach was not possible with the resources available. However, the magnitude of the 't' values indicates the relative weight that can be placed on the analyses, and it seemed reasonable to conclude that the treatments could be ranked $C < D < B \leqslant E < A$ on the basis of tuber N.

Of the differences in tuber yield per hill for small seed tubers the difference between C and A is highly significant. As these treatments had produced the most significant difference in tuber N but equal stem numbers per tuber, it was concluded that the differences in yield at small tuber weights was due to difference in tuber N.

Of the differences for large seed tubers, the only significant difference was between treatments B and C. These treatments had also produced respectively the lowest and highest stem numbers per tuber. The 't' value for this specific comparison for stem number was 2.80 ($t = 2.02$ when $P = 0.05$). It was therefore concluded that the significantly higher yield for large tubers from treatment B had been accentuated by a lower stem number.

Table 26 : Statistical analyses of differences in seed tuber N.

	Treatment				
	A	B	C	D	E
	1.82	1.40	1.53	1.37	1.76
	3.02	1.53	1.05	1.29	1.63
	1.84	2.32	1.18	1.29	1.62
	2.14	1.26	0.91	1.52	1.58
	1.64	1.58	1.78	1.32	1.50
N % D.M.	1.54	1.63	1.15	1.18	1.40
	1.34	1.07	1.05	1.19	1.29
	1.53	1.21	1.22	0.96	1.25
	1.44	1.12	1.01	1.03	0.99
	1.34	1.06	1.05	1.05	1.38
	1.77	1.42	1.20	1.22	1.44

't' value when C compared with				't' (P=0.05)
A	B	D	E	2.26
3.00 *	1.77	0.29	2.74 *	

Table 27 : Statistical analyses of differences in tuber yield per hill attributable to previous nutrient treatment of seed crop

Seed tuber Number	't' value when C compared with A	B	D	E	't' (P=0.05)
25 small	1.94	0.48	1.82	1.73	2.06
25	4.09 *	1.78	1.34	1.23	2.06
50	4.20 *	1.68	2.24 *	2.01 *	2.00
20 large		0.95	0.18	0.41	2.09
20		2.12 *	2.00 *	1.08	2.09
40		2.16 *	1.22	0.68	2.02
90 overall		2.70 *	0.93	0.99	1.99

d) Tuber yield and tuber number

Two possible causes of the differences in tuber yield were considered. One was that the individual tubers were of different sizes (due to a different growth period or growth rate or both). The other was that there were differences in the numbers of tubers produced. To test the latter hypothesis, the total tuber numbers per hill were compared.

Table 28 : Effect of previous nutrient treatment on tuber number per hill

	Treatment				
	A	B	C	D	E
Small seed	19.4	17.4	16.2	19.0	17.0
Large seed		28.2	27.6	29.3	26.3
Overall		22.8	21.9	24.2	21.7

There is no clear relationship between previous treatment and tuber number but certainly for the small seed tubers, the maximum difference was between treatments A and C. The 't' value for this specific comparison was 3.18 ($t = 2.02$ when $P = 0.05$). In this case, the lower yield was associated with a lower tuber number.

5 iii) Studies in 1968

Two experiments were laid down, one in Cornwall and one at Wellesbourne, but the early potato season was late and only the yield results from the Cornish experiment were available for inclusion in this thesis. However, both experiments will be described to illustrate the way in which the methods of approaching the problem were developed.

a) Cornwall - Commercial Evaluation Experiment

One aim of the work had been to see if there were yield differences, attributable to nutrient treatment of the seed crop, which might be commercially significant under British conditions. It was reasoned that an attempt at commercial evaluation ought to be made in an area where a large proportion of the earliest potatoes are produced, such as Cornwall. An experiment was therefore planned at Rosewarne E.H.S., Camborne, Cornwall, in which only the tuber size traditionally used for early production would be used rather than attempt to study the effect of previous treatment over a whole range of tuber sizes.

The statistical lay-out chosen was a "Latin Square with column added" (Pearce, 1952), as it was considered that such a design would account for any systematic error introduced during the ridging as well as random differences in soil fertility. Each row comprised two ridges, and each plot comprised 20 plants i.e. two 10 plant rows. There were five plots per treatment.

In early February, 100 seed tubers weighing 60-70 g were selected from each of the five sources grown in 1967, and each set of 100 was

divided into five sets of 20 tubers, the average weight being 65 g ± 0.3 g. Just prior to despatch to Rosewarne, the number of eyes with visible sprouts per tuber was noted. Once at Rosewarne, the tubers were handled in the same way as those used in other trials in progress. They were planted on February 23rd at a depth of 4" in ridges 30" apart, with a 12" spacing within the ridge. The soil which had received F.Y.M. at 10 t.p.a. + 120 units N, P_2O_5 & K_2O. was a high yielding brown loam. Unfortunately a spell of cold weather then followed, and the stems did not begin to emerge until April 18th, making this season abnormally late.

There were virtually no differences between treatments in the times of emergence.

The plants were harvested on June 17th. Records taken were limited to the total tuber yield and total stem number per plot. In addition, the numbers of branched (secondary) stems arising from the main stems (as defined by Toosey, 1963) were counted.

A summary of the data is given in Table 29a, and the statistical analysis of the yield data presented in Table 29b.

Table 29a : Effect of previous nutrient treatments on tuber yield (kg), main stems, and secondary stems per 100 hills - 1967 seed crop, grown on in Cornwall

	Treatment			
	NPK	NP	K	Nil
Tuber yield (kg)	40.640	43.190	36.842	33.895
Main stems	329	309	287	307
Secondary stems	12	16	23	40
Total stems	341	325	310	347

Table 29b : Analysis of variance of differences in tuber yield per plot (20 hills) according to Pearce (1952)

K	7.000	NPK	7.964	NP	9.777	Nil	6.490	NPK	8.984
NPK	7.850	Nil	6.461	K	8.389	NP	8.700	K	7.567
NP	8.275	K	6.093	Nil	5.951	NPK	6.632	Nil	7.170
Nil	7.822	NP	8.105	NPK	9.210	K	8.077	NP	8.332

Variance Ratio	'F' (P=0.05)
7.26 *	3.86

Adjusted mean tuber yield

Seed treatment NP = 8.55 ± 0.32 kg
NPK = 8.08
K = 7.40
Nil = 6.93

S.E. difference between 2 adj. means

0.45 kg

l.s.d. (P=0.05)

1.02 kg

It is clear that the high N treatments (NPK and NP) produced tubers which outyielded tubers from the low N treatments (K and Nil). The high N of the NP tubers more than counteracted the two week delay in the time of appearance of sprouts when compared with the NPK tubers. However, at low N, the increase in yield of the K tubers over the Nil tubers might be explained by the slight advance in sprouting of the former. A further noticeable effect is the increase in the number of secondary branches from 12 per 100 hills in the NPK treatment to 40 per 100 hills in the Nil treatment. This may have accentuated any differences resulting from differences in the supply of N from the seed tubers.

b) Wellesbourne - effects of previous balanced high and low fertility on emergence and yield from small seed tubers

Although the important distinction between the effects of previous nutrient treatment on time of sprout appearance and subsequent sprout growth was discovered as a result of using imbalanced nutrient treatments, the final effects of such treatments on tuber field performance were consequently more difficult to forecast. It was therefore decided to concentrate on the balanced treatments, NPK and Nil. It was also decided to limit further study to small tubers (up to 50 g) for two reasons. One was that differences in yield in the previous year produced by previous nutrient treatment were more pronounced. The other was that it seemed pertinent to examine the possibilities of using smaller seed in view of the problems of seed bulk stressed in the introduction.

Accordingly, six sets of 50 seed tubers from treatments NPK and Nil of the 1967 seed crop weighing 5 - 50 g were carefully matched for weight. Four sets were for replicates in the field experiment, and two were for sprout weighings before planting and at the time of emergence.

Reducing the treatment number to two simplified designing the experiment. It was decided to draw up a set of 24" ridges as in 1967, lay out four blocks along the line of the ridges and to position the treatments at random within the block. For statistical analysis treatment Nil would be used as a standard against which to compare treatment NPK using the 't' test.

One modification in the planting procedure was adopted. In 1967, a "pot-holer" had been used to prepare holes in which to drop the seed tubers. This meant that the apical sprouts on large tubers were nearer the surface than those on the smaller tubers. In 1968, as the medium-yielding sandy loam had a better tilth than the low-yielding sandy soil used in the previous year it was decided to push the tubers into the tops of the ridges to a constant depth. This also ensured that the seed tubers were always planted rose-end uppermost.

Prior to planting, the lengths of the sprouts on each tuber were measured as an added estimate of the differences between the tubers, although such a measure was less accurate than weighing. These figures are summarized in Table 30.

Table 30 : Effect of previous nutrient treatment on average sprout length (mm).

	Treatment			
	Nil	NPK	Diff	$Diff^2$
I	3.6	5.2	1.6	2.56
II	3.8	5.2	1.4	1.96
III	3.8	5.1	1.3	1.69
IV	3.9	5.3	1.4	1.96
	15.1	20.8	5.7	8.17
	3.8	5.2	1.4	

't'	't' (P=0.05)
20.0 *	3.18

The mean values for the sprout weighings carried out at times related to the progress of the field experiment are presented in Tables 31 a and b. It can be seen that the relative difference between the two treatments was less at the second assessment. However, the three-fold difference in the proportion of tubers with visible stolons probably increases the physiological significance of the difference.

Table 31 : Differences in sprout growth in store due to previous nutrient treatment

a) At the time of planting of field experiment (April 19)

	Treatment	
	NPK	Nil
Mean tuber weight (g)	22.9	22.9
Total sprout weight/tuber (mg)	247	100
Mean largest sprout weight/tuber (mg)	114	65
Mean sprout weight (mg)	68	36
Sprout Number	2.9	2.2

b) At the time of 95% emergence of field experiment (May 17)

	Treatment	
	NPK	Nil
Mean tuber weight (g)	22.9	22.9
Total sprout weight/tuber (mg)	683	460
Mean largest sprout weight/tuber (mg)	300	207
Mean sprout weight (mg)	194	139
Sprout Number	3.5	3.3
% tubers with stolons	15	5

The experiment was planted on April 22nd and the first plants emerged on May 3rd. Daily emergence counts were then made. The statistical comparison of the differences recorded 18 days after planting, when about 75% of the plants had emerged, is shown in Table 32.

Table 32 : Effect of previous nutrient treatment on emergence of seed tubers at Wellesbourne - numbers of plants out of 50 emerged 18 days after planting

	Treatment			
	Nil	NPK	Difference	$(\text{Difference})^2$
I	40	44	- 4	16
II	40	45	- 5	25
III	35	42	- 7	49
IV	35	47	- 12	144
Σ	150	178	- 28	234
$\bar{x}$	37.5	44.5	- 7	

't'	't' (P=0.05)
3.93 *	3.18

A further assessment of differences in haulm growth was made by counting the number of main stems in the field rather than waiting until the plants had been harvested. It is impossible with such an assessment to clearly differentiate between primary stems, and those which may have branched under the surface to give two secondary stems, as was done at Rosewarne. However, it was reasoned that as the tubers had been planted fairly near the surface, as is good practice for early potato production, such errors would be minimal. The numbers

of secondary stems were to have been counted at harvest. The results are summarized in Table 33.

Table 33 : Effect of previous nutrient treatment on number of main stems per hill - June count

	Treatment			
	Nil	NPK	Difference	(Difference)^2
I	2.9	2.8	+ 0.1	0.01
II	2.5	2.7	- 0.2	0.04
III	2.6	2.8	- 0.2	0.04
IV	2.5	3.0	- 0.5	0.25
Σ	10.5	11.3	- 0.8	0.34
m	2.6	2.8	- 0.2	

't'	't' (P=0.05)
1.63	3.18

Thus the small differences recorded were not significant.

No further details are available from this experiment.

5 iv) Discussion

Although the level of tuber K is important in determining the eye number/tuber weight relationship and the time of appearance of sprouts on those tubers, it is clear from the first field experiment at Wellesbourne, and the commercial evaluation experiment in Cornwall, that seed tuber N is more important in determining the final yield of the subsequent crop. For seed tubers weighing less than 50 g this seems to be due to some qualitative changes, possibly in the seed tuber reserves, rather than in changes in the number of stems produced by that tuber. For larger seed tubers, however, the effects may have been accentuated by differences in stem number.

In the first field experiment at Wellesbourne the nutrient treatments had been such that the effects of differences in tuber K and N were counter-acting each other. In the second experiment, from which the yield results are not available, there was no such counter-action resulting from the balanced nutrient treatments used. Such treatments might at first sight be the obvious choice for commercial use. However, the biggest yield in Cornwall was from seed tubers produced under treatment NP which had produced visual symptoms of K deficiency in the seed crop.

It was therefore concluded that seed tuber N was the over-riding factor in explaining yield differences produced by previous seed crop nutrition.

THE EFFECTS OF NUTRIENT TREATMENTS OF POTATO PLANTS ON THE PERFORMANCE OF THEIR PROGENY

6 : The effects of nutrient treatments of potato plants on the performance of their progeny

6 i) Discussion

The present research has established that the nutrient treatment given to the seed crop can affect:-

1 : The eye number/tuber weight relationship of the seed tubers.

2 : The mechanisms controlling the sprouting of the seed tubers and the time of sprouting.

3 : The proportion of eyes on the seed tubers which produce visible sprouts, and the numbers of sprouts eventually produced.

4 : The subsequent pattern of sprout growth.

5 : Stem growth and tuber yield obtained from the seed tubers following normal planting in the field.

Generally, differences in the seed tubers prior to planting (1, 2 and 3, above) were related to the K content of the tubers, whilst the over-riding factor affecting the field performance (4 and 5, above) appeared to be related to the seed tuber N content. These two categories of effect will now be discussed.

Differences in the eye number/tuber weight relationship of seed tubers of three potato varieties have been related to differences in their mineral composition (p.32) and references cited which showed that a range of mineral composition was likely to arise in commercial seed crops as a result of differences in soil fertility, spacing and locality. The rate of increase of eye number with tuber weight fell

as tuber N increases whilst the eye number on tubers of a given weight fell as tuber K increased.

Tuber K was also shown to be inversely related to the level of a fluorescent acid inhibitor extracted from dormant seed tubers. It was not possible to identify conclusively this compound but the evidence presented in Section 3, iii, suggests that it may be a glycoside of scopoletin.

It is now proposed to relate the known properties of scopoletin and its glycosides to the present study.

It is generally accepted that reversible inhibition is expressed through enzymes. The currently accepted theory of the mechanism of enzymic inhibition is that mainly developed by Monod (1966). Briefly, he suggests that there are three sites on the protein part of enzymes which are occupied by the enzyme substrate, the enzyme activator, and the enzyme repressor. When the activator is in position, the enzyme is structurally able to accommodate the substrate molecule. When the repressor is in position, the enzyme is stressed, and neither activator nor substrate can be accommodated. In his review article, cited above, Monod suggests that phenyl β glycosides have structures suitable for activity in such activator/repressor complexes. This group of compounds would include the glycosides of scopoletin.

It has been suggested by Sargent and Skoog (1961) that scopoletin glycosides and scopoletin are in equilibrium. They further suggest that scopoletin may be directly involved in cell wall

synthesis, and note that high levels of scopoletin are induced in tobacco callus tissue by high auxin levels, giving the tissue a high capacity for bud formation. The demonstration by Wahkloo (1965) that high tissue K in Solanum nigrum resulted in high auxin levels has already been noted.

The data presented in this study show that tubers with high K levels produced visible sprouts some two to three weeks before tubers with a low K content. At this stage a greater percentage of the eyes on high K tubers had sprouts visible than on low K tubers.

These data can be explained by the hypothesis that high tuber K is related to a high level of scopoletin, and therefore a high capacity for cell wall synthesis which is a pre-requisite for sprouting. High tuber K is also related to a low level of a related glycoside of scopoletin which is active in delaying sprouting.

High tuber N was related to a high level of the inhibitor, and delayed sprouting, which supports this hypothesis. However, once sprouting had begun, the pattern of sprout growth was positively related to high tuber N. Thus there was less correlative inhibition, and sprout growth rate was higher. This apparent contradiction can be explained in terms of a recently published model of seed dormancy (Amen, 1968). Amen proposes a cybernetic model, divided into four stages.

1. Inductive mechanism - those ontogenetic events which lead to the onset of dormancy.

2. Cryptobiotic control mechanism - the formation and maintenance of metabolic blocks.

3. Trigger mechanism - those transient agents and their products which are sensitive to specific environmental stimuli which function as metabolic activators.

4. Germination mechanism - the initiation of cell proliferation which includes:-

a) Enzyme activation

b) Degradation of insoluble foods

c) Translocation of soluble foods

d) Mobilization of nutrients

e) Synthetic reactions of growth

Terman (1953) has shown that increases in soil K up to an optimum can result in increases in the dry matter content of potato tubers, whilst Steck (1954) has related the complexity of carbohydrate storage molecules to tissue K levels, reducing sugar being predominant at low K. Conversely Burton (1966) notes that high N treatments also result in an increase in tuber sugar levels. Carbohydrates are translocated from storage organs in the form of sugars. (Edelman, 1963). It is therefore suggested that, in tubers with a high N level, although the "cryptobiotic dormancy control mechanisms" are more active thus extending dormancy, once the "germination mechanisms" have begun operating, the "translocation of soluble foods" can proceed

more quickly.

It now remains to suggest an explanation for differences in the operation of the "trigger mechanism" which ends dormancy. Amen (loc. cit) envisages a range of mechanisms, one of which is simply time. Burton (1963) suggests that dormancy commences at tuber initiation in the potato seed crop. In 1967 samples were taken during the growth of the seed crop for hormonal analysis and also to see whether there were any differences in the time of tuber initiation attributable to the nutrient treatments. Unfortunately the first sample was taken too late, and it was impossible to estimate the time of tuber initiation with any precision. However, the time of emergence of the parent potatoes planted to produce the seed crop was related to nutrient treatment. These differences indicated early effects of nutrients on the seed crop, and could be taken as indicative of differences in the time of tuber initiation. This implies, on the basis of the above theories, that dormancy began at different times i.e. there were differences in the "Inductive Mechanism" of dormancy. However, the data supporting this view is scanty and further work is essential to resolve the issue.

Having suggested a mechanism accounting for the different effects of tuber K and tuber N on dormancy and sprouting, it is now, proposed to consider the striking and over-riding effect of seed tuber N related to yield differences.

If the explanation of differences in the operation of the

"trigger mechanism" in ending dormancy is accepted, it follows that the seed tubers had slightly different physiological ages. Thus, the high N seed tubers may have been initiated later than the low N tubers and were consequently younger. Madec and Perennec (1959) concluded that the time required before tuber initiation occurred appeared to be influenced by the physiological age of the seed tuber. Iritani (1968) showed that physiologically young seed tubers sprouted in store and emerged in the field more slowly than old seed tubers, but gave a higher tuber yield. The data reported here shows the same pattern for seed tubers with high N levels. It was also noted that the high N seed tubers in store had produced more sprouts with stolon-like branches at the time of emergence of plants from similar seed tubers planted in the field. It is therefore suggested that the observed yield differences related to seed tuber N could be mainly due to differences in the time of tuber initiation on the seed crop.

It is relevant to emphasize here that there was liftle effect of stem numbers in producing these differences in yield - thus in the 1967 experiment at Wellesbourne, the maximum yield differences recorded were between seed tubers from two nutrient treatments which had produced identical stem numbers. The general question posed at the beginning of this study was : "Can differences in seed tuber performance due to previous nutrient treatment be explained solely on the basis of differences in stem number per seed tuber, or do other aspects of performance contribute?" On the basis of the results

presented here, the conclusion is that the observed yield differences were not produced by the differences in stem number and that other aspects of performance are more important, the over-riding factor being a qualitative difference related to seed tuber N such as time of initiation of tubers in the field.

The practical implication of this conclusion for commercial seed production is that weight for weight, seed tubers with a high N content (and a low K content) can give a higher early yield than low N seed tubers. The traditional practice is to produce seed tubers low in N. Thus M.A.F.F. (1965) suggest that "in view of the lack of experimental data on manuring of seed crops in ware areas, specific recommendations cannot be made. Traditional recommendations suggest lower rates (especially of N) for seed crops, presumably to ensure a maximum yield of seed sized tubers." Treatment NP applied to the 1967 seed crop produced plants which have the greatest number of small tubers, as can be seen from table 34.

Table 34 : Effect of nutrient treatment on tuber size and number 1967 seed crop

	Treatment			
	NPK	NP	K	Nil
Total tuber number per 20 plants	200	207	166	152
Tubers weighing less than 50 g	106	140	97	130
Maximum tuber weight (g)	440	296	185	142

This was probably because of the deficiency of K induced by this treatment. However, the 1967 nutrient treatments were based on the

recommendations for manuring of seed potatoes (M.A.F.F. Bull. 94). The NPK treatment was therefore imbalanced in favour of K. Mackay (1966) has suggested that the optimum nutrient levels for potatoes under Canadian conditions are 6.5% N, 0.5% P and 3.9% K i.e. a balance well towards N. In practice, the best results may be obtained by a greater control of N and K applied, and restricting the individual tuber size by a high planting density. This in turn would result in a lower tuber N level but this could probably be overcome by top dressings of fertilizers.

The importance of the ratio of N to K appears to be related to the counter-acting effect of N and K on performance. Having recognised the mechanisms involved, it should be possible to modify them. Thus, breeders could aim for a low activity of the "cryptobiotic control mechanisms" involved in tuber dormancy, (using fluorescence of tuber extracts for screening suitable material) coupled with highly active "germination mechanisms". The differences in seed tuber performance due to previous nutrient treatment might be expected to be maximal in such a variety.

It is possible that such varieties exist. There is certainly evidence for characteristic fluorescence under u/v of varieties with long dormant periods (Whitehead et al, 1953) and for varietal differences in the amount of sugar available in the seed tubers after storage (Burton, 1966). A survey of the u/v fluorescence, as defined in this study, on a range of varieties with different dormancies and

sprouting behaviour, and related to their N and K contents as well as "soluble food" reserves such as sugars and soluble N, should enable inter-varietal differences in yielding performance to be understood much more fully, and perhaps modified where appropriate. At the same time it would be possible to establish how much these analyses varied between different commercial sources of the same variety.

Finally it must be emphasized that the work presented here was planned as a general study on differences in seed tuber performance related to previous nutrient treatment. Differences have been clearly demonstrated, and certain general principles indicated. These principles have still to be verified, and examined in detail. Thus, the effect of varying N/K ratios on time of tuber initiation on the parent potatoes planted to produce the seed crop, and on the seed tubers in the following year should be examined. The fluorescent compounds related to tuber dormancy have still to be conclusively identified. The existing variation in the factors studied due to different seed source has to be determined. The possibility of inter-varietal differences in these factors has already been mentioned.

When this work has been done, it should be possible to control seed tuber performance to a much greater extent. This greater control should not only be of value in physiological studies but may also have some commercial value.

6 ii) Conclusions

1 : The previous nutrient treatment of the seed crop can affect the subsequent performance of the seed tubers of the early variety studied.

2 : High seed tuber K was related to:-

a) fewer eyes per unit weight of tuber

b) low levels of a fluorescent acid inhibitor active in delaying sprouting

c) a shorter time to 50% sprouting

d) a greater proportion of eyes producing visible sprouts

e) increased correlative inhibition of the resulting sprouts

3 : High seed tuber N was related to:-

a) a lower rate of increase of eye number with tuber weight

b) high levels of the acid inhibitor

c) a delay in 50% sprouting

d) decreased correlative inhibition of the sprouts

e) high sprout growth rate

4 : The balance of these counter-acting differences can result in early yield increases when the seed tubers are grown on in the field.

5 : The over-riding factor for such increases in early tuber yield is seed tuber N.

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8

REFERENCES

8 : References

Titles in brackets are translations.

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APPENDICES

APPENDIX 1

Computer program used to fit

log. eye number / log. tuber weight regressions

Language : Extended Mercury Autocode

Program document : NVDPHGM/EYEANDWT/LOGREGRE/SSIONS

Summary : The program fits regression of $\log_e(E - E_o)$ on $\log_e W$ for a given set of E_o values. It prints the sums of squares and products of $\log_e(E - E_o)$ and $\log_e W$ in addition to the fitted parameters and RSS.

data form:-

DATA TITLE	DATA TITLE : RECORD 1965
No. of E_o values	2
E_o values	0 1
Tuber No.	182
Eye No. Tuber Wt	3 2.4 3 4.8

APPENDIX 2

Routines used in determing Tuber N, P and K

As used by the Chemistry Section,

N.V.R.S., Wellesbourne, 1968.

1: Preparation of plant ash solution

Approximately 0.1 g ground plant material is placed in a weighing tube and dried overnight at 100°C. After cooling in a dessicator, the plant material is accurately weighed into a digestion tube. 2 ml conc. sulphuric acid followed by 1 ml hydrogen peroxide are added. The tube is heated on an electric heater until fumes of the acid begin to condense on the walls of the tube, which is then cooled, more peroxide added, and then the tube reheated. The addition of peroxide is repeated (cooling before each addition) until all organic matter has been destroyed. Heating is continued for 20 minutes after the last addition of peroxide.

When cold, the digest is transferred quantitatively to a 50 ml volumetric flask with distilled water and made up to the mark. This solution is referred to in the subsequent sections as the plant ash solution.

2: Determination of N in plant ash solution

5 ml plant ash solution are pipetted into a Markham still, about 5 ml 40% sodium hydroxide solution added, and steam distillation commenced. The distillate is collected in a 50 ml Erlenmeger flask containing 1P ml 1% boric acid, the condenser outlet dipping into the acid solution. After about 10 ml of distillate have been collected, the flask is lowered and a further 2-3 ml distillate collected; this helps clear distillate from the lower end of the tube.

The distillate is titrated against N/140 sulphuric acid using two drops of mixed methyl red/bromocresol green indicator to determine the end-point. The normality of each batch of acid is checked against a standard N solution prepared by dissolving 2.3600 g oven dried ammonum sulphate in water, adding 1 ml conc. sulphuric acid, and made up to 500 ml. 5 ml of this solution are passed through the complete procedure, and the distillate is titrated against the N/140 sulphuric acid. This should take 5 ml of acid.

1 ml acid ≡ 100 mg. N in the plant ash solution

3: Determination of P in plant ash solution

Duplicate 5 ml aliquots of plant ash solution are pipetted into two test tubes. To each is added 5 ml of a vanado-molydate/ sodium acetate reagent. The tubes are shaken and left for a minimum of 20 minutes before measuring the optical density in an EEL portable colorimeter using a blue filter (OB10).

With each batch of samples, a series of standard solutions containing 0, 2, 8, 12, 16, 24 and 32 p.p.m. P are passed through this procedure, and a calibration curve drawn, from which the phosphorus contents of the unknowns can be read.

4: Determination of K in plant ash solution

An aliquot of the plant ash solution is diluted 1.10 with distilled water and the K content of this solution determined using

an EEL flame photometer. Two solutions are used to calibrate the instrument - the reagent blank solution, and a 5 p.p.m. K solution which are arranged to give deflections of 0 and 50. Frequent checks are made with these two solutions during the measurement of a batch of samples.

APPENDIX 3

Computer print-out of

log. eye no. / log. tuber wt. regressions

A = 1965 seed crop var. "Record"

B = 1966 " " " "Craigs Alliance"

C = 1967 " " " " "

Legend

1 = Sample No.

W = Log. Tuber Weight

WW = Uncorrected Sum of Squares of W

X = Log. Eye No.

XX = Uncorrected Sum of Squares of X

XW = Uncorrected Sum of Products

VAM = Variation about mean

SLO = Slope of regression

INT = Intercept "

RSS = Residual Sum of Squares

A: Computer print-out for data from maincrop var. 'Record' 1965

Treatment	1	W	WW	X	XX	XW	VAM	SLO	INT	RSS
Nil	48	168.315	602.361	96.314	195.458	340.811	2.1984	0.2533	1.1183	1.4184
K	62	225.121	830.026	121.575	241.260	445.865	2.8654	0.3510	0.6864	1.3110
N	89	304.452	1053.244	182.448	376.513	626.797	2.5001	0.2276	1.2715	1.8904
NK	104	383.076	1433.767	206.120	413.593	765.198	5.0780	0.2626	1.0148	3.5106
P	53	183.007	640.886	108.123	223.985	375.710	3.4098	0.2638	1.1290	2.7856
PK	79	287.551	1065.815	161.441	333.102	592.956	3.1898	0.2817	1.0310	1.7068
NP	55	184.995	629.894	105.595	204.083	356.382	1.3517	0.1580	1.3884	1.1606
NPK	101	381.414	1463.198	181.497	332.807	692.511	6.6570	0.3114	0.6211	4.4430

B: Computer print-out for data from early var. 'Craigs Alliance' 1966

Treatment	1	W	WW	X	XX	XW	VAM	SLO	INT	RSS
K_1P_4	225	648.824	2036.011	451.296	918.874	1327.857	13.684	0.1604	1.5432	9.438
K_3P_1	228	786.671	3011.939	436.548	852.553	1549.709	16.701	0.1461	1.4107	10.350
K_2P_4	232	778.682	2954.854	428.371	813.623	1492.681	22.667	0.1609	1.3065	13.835
K_4P_4	188	682.214	2781.921	359.392	706.991	1357.482	19.955	0.1741	1.2800	10.674
K_4P_3	214	741.927	2955.575	394.763	753.073	1436.269	24.860	0.1765	1.2329	12.923
K_1P_3	185	502.169	1512.479	350.463	678.337	980.212	14.421	0.1935	1.3691	8.828
K_2P_4	232	778.682	2954.854	428.371	813.623	1492.681	22.667	0.1609	1.3065	13.835
K_2P_3	179	655.151	2592.098	343.350	673.563	1282.036	14.965	0.1306	1.4403	11.655
K_3P_2	207	707.861	2749.385	384.418	727.651	1350.427	13.753	0.1091	1.4840	9.841
K_4P_3	211	762.757	3033.851	414.572	831.487	1534.888	16.938	0.1310	1.4912	12.192

C: Computer print-out for data from early var. 'Craigs Alliance' 1967

Treatment		1	W	WW	X	XX	XW	VAM	SLO	INT	RSS
Nil	1	152	494.227	1712.497	300.558	605.488	1002.202	11.177	0.2363	1.2089	5.2831
	2	90	265.539	837.748	158.904	286.002	481.294	5.440	0.2294	1.0887	2.5818
K	1	167	607.655	2366.758	330.349	665.751	1237.355	12.274	0.2269	1.1526	4.2581
	2	156	532.996	1989.524	285.988	536.370	1014.860	12.080	0.2240	1.0679	3.6250
NP	1	207	659.568	2489.619	410.506	833.961	1376.948	19.880	0.1777	1.4170	7.6289
	2	194	623.000	2299.048	397.189	828.543	1323.326	15.350	0.1603	1.5328	7.6871
NPK	1	200	742.401	3176.685	480.410	741.107	1485.509	17.548	0.1744	1.2545	4.7385
	2	180	673.126	2798.873	350.836	696.817	1358.064	13.006	0.1636	1.3373	5.4666

APPENDIX 4

Seed tuber performance in the field

1966 Seed crop, var. "Craigs Alliance"

TREATMENT A

			MIN	MEAN	MAX
VAR	1	= MOTHER TUBER WEIGHT G	5.60000	30.48400	49.3000
	2	= EYE NO.	5.00000	7.08000	10.0000
	3	= STEM NO.	2.00000	3.28000	7.0000
	4	= DAYS TO EMERGENCE	24.00000	27.52000	38.0000
	5	= TUBER YIELD G/HILL	38.10000	205.86800	366.9000
	6	= TUBER NO./HILL	7.00000	19.42000	34.0000
	7	= TUBER YIELD G/STEM	12.70000	65.48400	144.7500
	8	= MEAN TUBER WEIGHT G	5.03462	10.82090	20.8143

VARIATE 1

5.6	6.5	9.7	10.3	13.4	14.3	16.1	19.6	19.7	22.6
22.6	23.2	23.6	25.1	25.3	25.5	25.7	26.0	26.6	27.4
27.4	27.5	27.6	28.2	28.6	28.8	31.6	32.0	32.2	33.4
34.3	36.6	37.8	38.9	39.7	40.1	40.8	41.3	41.5	41.7
41.9	42.4	42.6	43.0	43.2	43.2	45.1	46.3	48.4	49.3

MEAN 30.5

VARIATE 5

95.7	79.1	38.1	104.3	126.0	190.0	277.2	115.1	172.5	84.3
160.2	115.6	179.0	298.2	86.5	199.6	244.2	168.0	146.3	192.1
165.6	190.2	215.0	216.5	278.4	236.8	288.3	131.4	299.3	119.5
280.8	175.3	243.6	291.4	260.2	239.9	366.9	284.7	253.1	289.5
231.9	166.2	276.1	130.9	263.3	250.6	210.7	283.4	323.5	258.4

MEAN 205.9

VARIATE 2

6	7	5	7	6	6	5	6	6	6
7	9	7	8	5	6	9	6	6	8
8	7	5	7	7	7	5	8	7	7
8	9	10	8	10	7	10	6	6	7
7	10	8	7	5	7	8	9	5	8

MEAN 7

VARIATE 3

3	3	3	3	3	4	3	3	2	2
5	3	3	4	4	4	3	3	2	3
3	3	2	4	3	3	3	2	4	3
3	3	2	3	5	4	7	4	3	2
4	3	5	3	4	3	2	4	4	3

MEAN 3

VARIATE 4

26	35	36	35	31	33	27	25	31	38
29	29	31	25	28	27	26	26	31	24
25	25	26	29	27	24	25	35	24	27
24	24	29	28	25	26	24	26	24	27
26	25	26	28	28	25	27	24	24	26

MEAN 28

VARIATE 6

14	7	7	17	17	24	23	16	14	12
21	19	14	27	7	22	18	24	18	11
17	15	20	24	28	15	25	10	29	13
16	20	19	14	25	22	34	23	16	23
23	13	26	26	23	17	21	33	23	26

MEAN 19

VARIATE 7

31.9	26.4	12.7	34.8	42.0	47.5	92.4	38.4	86.3	42.2
32.0	38.5	59.7	74.6	21.6	49.9	81.4	56.0	73.1	64.0
55.2	63.4	107.5	54.1	92.8	78.9	96.1	65.7	74.8	39.8
93.6	58.4	121.8	97.1	52.0	60.0	52.4	71.2	84.4	144.8
58.0	55.4	55.2	43.6	65.8	83.5	105.4	70.9	80.9	86.1

MEAN 65.5

VARIATE 8

6.8	11.3	5.4	6.1	7.4	7.9	12.1	7.2	12.3	7.0
7.6	6.1	12.8	11.0	12.4	9.1	13.6	7.0	8.1	17.5
9.7	12.7	10.8	9.0	9.9	15.8	11.5	13.1	10.3	9.2
17.5	8.8	12.8	20.8	10.4	10.9	10.8	12.4	15.8	12.6
10.1	12.8	10.6	5.0	11.4	14.7	10.0	8.6	14.1	9.9

MEAN 10.8

TREATMENT B

			MIN	MEAN	MAX
VAR	1	= MOTHER TUBER WEIGHT G	5.30000	54.15330	142.9000
	2	= EYE NO.	4.00000	7.04444	11.0000
	3	= STEM NO.	1.00000	4.11111	9.0000
	4	= DAYS TO EMERGENCE	23.00000	26.64440	36.0000
	5	= TUBER YIELD G/HILL	42.70000	226.58900	410.1000
	6	= TUBER NO./HILL	6.00000	22.22220	43.0000
	7	= TUBER YIELD G/STEM	10.87500	62.20940	182.2000
	8	= MEAN TUBER WEIGHT G	4.35000	10.45700	26.5250

VARIATE 1

5.3	6.6	9.7	10.3	13.7	14.2	16.4	19.6	19.6	20.8
20.9	21.7	23.2	23.5	23.8	23.9	24.8	24.9	24.9	26.1
26.2	26.7	27.5	28.3	30.1	30.6	31.0	32.3	32.6	33.8
35.7	38.3	38.3	38.4	39.1	39.4	39.5	40.5	40.6	41.4
41.8	42.1	42.2	42.4	42.7	43.3	43.4	44.1	44.5	44.9
56.0	56.6	60.7	63.2	64.3	67.7	68.2	70.5	71.1	71.2
71.5	72.6	74.1	75.4	77.0	77.5	77.6	77.8	79.8	82.0
82.5	86.2	86.4	86.6	86.6	86.9	92.4	94.0	95.5	95.6
97.4	97.5	97.6	100.1	100.4	103.2	103.3	108.5	119.8	142.9

MEAN 54.2

VARIATE 5

47.2	103.1	42.7	104.8	122.2	70.4	43.5	146.7	182.2	165.1
77.0	152.6	136.0	60.6	238.5	177.6	226.2	155.5	151.3	222.8
135.4	164.9	145.3	164.2	290.6	179.6	288.3	173.8	270.4	147.3
108.8	257.4	190.9	172.7	202.7	237.5	230.9	234.6	244.5	218.7
137.6	201.7	233.2	212.0	280.0	175.9	182.5	246.4	157.5	274.9
229.0	279.7	244.4	266.7	254.8	337.7	212.5	251.3	212.2	275.8
361.3	197.8	357.1	319.1	385.0	293.0	280.3	254.4	164.7	278.2
284.7	227.1	200.8	384.4	249.6	327.5	400.5	405.6	371.6	281.7
248.2	248.9	260.8	410.1	291.2	284.7	298.2	329.4	350.6	301.2

MEAN 226.6

VARIATE 2

6	6	7	6	6	5	7	4	6	5
4	5	7	5	8	5	5	8	6	6
7	6	8	6	6	6	5	6	6	8
6	6	7	7	7	8	5	7	7	8
7	8	4	5	9	5	5	6	6	9
8	8	6	8	8	7	6	7	10	6
7	7	10	7	9	9	10	8	7	10
9	7	6	9	10	6	10	8	8	7
11	9	10	7	7	7	9	7	8	8

MEAN 7

VARIATE 3

3	2	2	2	2	1	4	3	1	3
2	2	4	2	3	4	3	4	1	3
2	2	3	5	4	1	3	4	4	4
2	5	4	3	4	5	4	5	5	6
2	3	2	3	4	2	3	3	6	5
3	6	4	6	6	5	3	5	3	7
6	2	6	6	8	3	5	5	6	4
2	4	5	7	6	3	9	8	4	7
9	6	6	6	6	6	3	6	6	3

MEAN 4

VARIATE 4

26	30	35	24	34	25	28	29	29	26
36	24	24	36	28	24	29	29	23	26
30	32	27	31	26	25	24	27	30	31
24	24	24	25	24	29	31	26	27	26
24	30	24	28	26	25	27	25	33	24
24	30	23	26	24	23	24	25	33	25
24	25	26	31	23	25	24	23	32	28
27	24	24	26	23	24	24	24	24	24
27	29	24	24	33	25	25	24	25	26

MEAN 27

VARIATE 6

10	9	6	7	15	11	10	12	16	17
12	16	17	11	19	15	21	14	11	22
11	9	17	19	26	18	20	22	28	13
7	22	21	21	27	26	25	23	20	18
20	20	22	16	23	15	18	24	18	31
21	25	30	22	32	31	30	20	8	28
26	25	30	28	29	27	32	23	20	22
28	22	27	25	29	31	41	42	30	34
24	43	23	32	33	30	21	42	30	33

MEAN 22

VARIATE 7

15.7	51.6	21.3	52.4	61.1	70.4	10.9	48.9	182.2	55.0
38.5	76.3	34.0	30.3	79.5	44.4	75.4	38.9	151.3	74.3
67.7	82.4	48.4	32.8	72.6	179.6	96.1	43.4	67.6	36.8
54.4	51.5	47.7	57.6	50.7	47.5	57.7	46.9	48.9	36.5
68.8	67.2	116.6	70.7	70.0	87.9	60.8	82.1	26.3	55.0
76.3	46.6	61.1	44.5	42.5	67.5	70.8	50.3	70.7	39.4
60.2	98.9	59.5	53.2	48.1	97.7	56.1	50.9	27.5	69.6
142.4	56.8	40.2	54.9	41.6	109.2	44.5	50.7	92.9	40.2
27.0	41.5	43.5	68.3	48.5	47.5	99.4	54.9	58.4	100.4

MEAN 62.2

VARIATE 8

4.7	11.5	7.1	15.0	8.1	6.4	4.4	12.2	11.4	9.7
6.4	9.5	8.0	5.5	12.6	11.8	10.8	11.1	13.8	10.1
12.3	18.3	8.5	8.6	11.2	10.0	14.4	7.9	9.7	11.3
15.5	11.7	9.1	8.2	7.5	9.1	9.2	10.2	12.2	12.2
6.9	10.1	10.6	13.3	12.2	11.7	10.1	10.3	8.8	8.9
10.9	11.2	8.1	12.1	8.0	10.9	7.1	12.6	26.5	9.9
13.9	7.9	11.9	11.4	13.3	10.9	8.8	11.1	8.2	12.6
10.2	10.3	7.4	15.4	8.6	10.6	9.8	9.7	12.4	8.3
10.1	5.8	11.3	12.8	8.8	9.5	14.2	7.8	11.7	9.1

MEAN 10.5

TREATMENT C

			MIN	MEAN	MAX
VAR	1	= MOTHER TUBER WEIGHT G	5.50000	54.49110	144.1000
	2	= EYE NO.	4.00000	7.13333	12.0000
	3	= STEM NO.	1.00000	4.58889	9.0000
	4	= DAYS TO EMERGENCE	23.00000	27.30000	40.0000
	5	= TUBER YIELD G/HILL	53.80000	206.14600	369.2000
	6	= TUBER NO./HILL	7.00000	21.25560	44.0000
	7	= TUBER YIELD G/STEM	11.12000	50.23860	147.4000
	8	= MEAN TUBER WEIGHT G	4.27692	9.89955	16.0522

VARIATE 1

5.5	6.4	9.7	10.7	13.0	14.3	16.2	19.7	19.7	22.4
22.7	22.7	22.8	22.8	22.9	24.0	24.6	25.6	26.3	26.7
27.7	28.0	28.7	29.4	31.4	31.6	31.6	31.7	32.5	33.8
35.4	37.1	37.7	37.8	38.0	38.3	40.0	42.3	42.7	42.8
42.9	43.6	44.1	44.6	47.7	48.0	48.1	48.4	48.5	48.6
57.9	59.1	61.6	61.6	65.8	70.1	71.2	71.9	72.3	73.3
74.6	74.8	76.2	77.1	80.0	80.8	81.6	81.8	82.1	82.2
83.0	83.0	83.4	85.3	86.8	86.8	87.0	87.1	87.9	89.1
89.8	91.5	92.5	93.3	94.9	98.3	103.1	108.4	131.2	144.1

MEAN 54.5

VARIATE 5

67.4	92.0	154.7	85.9	153.6	86.2	97.7	147.4	155.1	55.6
88.7	219.8	189.0	153.5	141.5	124.9	152.4	222.1	216.9	170.7
91.8	53.8	82.5	154.3	215.7	112.5	188.8	216.0	154.1	134.3
144.2	269.1	195.7	129.4	177.3	117.7	189.0	222.2	114.9	250.9
227.5	145.4	319.0	98.3	112.4	254.9	230.0	184.1	234.0	157.5
159.8	122.8	270.1	369.2	170.4	301.0	242.5	315.9	195.9	300.0
304.8	213.1	258.6	332.0	227.3	188.6	284.0	329.5	237.8	306.7
185.4	154.3	235.5	315.2	311.7	336.7	276.4	339.0	262.7	282.0
320.3	223.0	249.1	332.3	330.4	312.4	324.0	241.2	148.7	290.4

MEAN 206.1

VARIATE 2

5	8	7	6	5	5	5	6	6	6
6	5	4	3	7	6	5	8	5	6
7	6	5	6	7	7	6	5	5	8
6	7	6	5	5	10	7	6	7	5
9	6	8	4	8	9	7	6	8	5
7	7	8	8	6	6	8	12	4	8
7	10	10	9	7	12	6	11	8	8
6	8	10	8	7	10	9	7	11	8
9	9	8	9	7	10	9	6	6	8

MEAN 7

VARIATE 3

1	2	2	2	2	1	2	1	2	5
2	5	2	2	2	4	2	4	3	4
4	4	2	4	2	4	5	3	2	3
3	3	2	3	3	3	4	5	4	4
5	5	5	5	3	4	5	5	8	5
4	7	6	7	4	5	8	6	4	6
5	7	7	8	7	3	6	5	5	6
5	3	7	5	5	7	7	8	7	7
7	5	7	7	6	7	6	7	8	9

MEAN 5

VARIATE 4

40	34	25	31	26	33	34	25	24	31
33	24	31	25	24	31	28	25	25	33
31	25	33	34	23	26	35	30	30	35
27	24	24	24	24	27	24	29	27	23
26	31	26	36	24	24	26	25	31	25
24	33	23	26	25	28	29	24	33	24
26	24	23	24	25	33	23	26	24	23
36	29	24	25	24	23	23	24	28	31
24	23	29	24	24	24	25	30	33	26

MEAN 27

VARIATE 6

8	12	13	13	10	9	12	11	11	13
12	21	18	14	14	19	16	18	20	11
8	7	9	11	19	14	15	19	17	14
12	27	22	13	19	9	19	23	9	21
27	24	27	15	12	28	28	26	23	19
25	18	30	23	22	20	21	34	18	30
33	29	30	33	27	17	27	29	28	32
20	19	22	27	34	37	31	35	19	27
44	25	22	30	32	34	30	34	23	31

MEAN 21

VARIATE 7

67.4	46.0	77.4	42.9	76.8	86.2	48.8	147.4	77.6	11.1
44.3	44.0	94.5	76.8	70.8	31.2	76.2	55.5	72.3	42.7
23.0	13.5	41.3	38.6	107.9	28.1	37.8	72.0	77.1	44.8
48.1	89.7	97.9	43.1	59.1	39.2	47.3	44.4	28.7	62.7
45.5	29.1	63.8	19.7	37.5	63.7	46.0	36.8	29.3	31.5
39.9	17.5	45.0	52.7	42.6	60.2	30.3	52.7	49.0	50.0
61.0	30.4	36.9	41.5	32.5	62.9	47.3	65.9	47.6	51.1
37.1	51.4	33.6	63.0	62.3	48.1	39.5	42.4	37.5	40.3
45.8	44.6	35.6	47.5	55.1	44.6	54.0	34.5	18.6	32.3

MEAN 50.2

VARIATE 8

8.4	7.7	11.9	6.6	15.4	9.6	8.1	13.4	14.1	4.3
7.4	10.5	10.5	11.0	10.1	6.6	9.5	12.3	10.8	15.5
11.5	7.7	9.2	14.0	11.4	8.0	12.6	11.4	9.1	9.6
12.0	10.0	8.9	10.0	9.3	13.1	9.9	9.7	12.8	11.9
8.4	6.1	11.8	6.6	9.4	9.1	8.2	7.1	10.2	8.3
6.4	6.8	9.9	16.1	7.7	15.0	11.5	9.3	10.9	10.0
9.2	7.3	8.6	10.1	8.4	11.1	10.5	11.4	8.5	9.6
9.3	8.1	10.7	11.7	9.2	9.1	8.9	9.7	13.8	10.4
7.3	8.9	11.3	11.1	10.3	9.2	10.8	7.1	6.5	9.4

MEAN 9.9

TREATMENT D

		MIN	MEAN	MAX
VAR 1 =	MOTHER TUBER WEIGHT G	5.20000	54.48560	153.5000
2 =	EYE NO.	3.00000	6.78889	10.0000
3 =	STEM NO.	1.00000	4.38889	8.0000
4 =	DAYS TO EMERGENCE	22.00000	25.93330	37.0000
5 =	TUBER YIELD G/HILL	28.90000	227.80400	459.9000
6 =	TUBER NO./HILL	6.00000	23.35560	47.0000
7 =	TUBER YIELD G/STEM	20.5833	57.41570	161.2000
8 =	MEAN TUBER WEIGHT G	4.81667	10.03730	17.9111

VARIATE 1

5.2	6.5	9.8	10.6	14.6	16.8	19.7	19.7	22.1	22.5
22.6	24.9	25.1	25.7	25.8	25.8	26.2	26.3	26.8	26.9
27.2	27.4	29.1	29.0	29.8	30.3	32.2	33.2	34.7	35.0
36.3	37.0	37.0	37.4	37.8	39.2	40.4	40.7	41.0	41.7
43.0	43.8	44.0	44.1	44.4	45.6	46.3	46.8	49.3	49.6
57.1	57.2	62.4	64.2	64.3	67.2	68.4	69.2	69.4	69.4
70.1	70.1	72.2	73.5	74.5	74.7	78.4	79.9	80.3	80.3
80.6	81.6	82.2	82.5	83.1	83.2	84.1	85.3	87.4	87.5
95.2	99.2	102.2	103.4	104.1	107.2	110.6	112.7	118.4	153.5

MEAN 54.5

VARIATE 5

96.1	28.9	161.2	116.7	110.1	128.8	124.7	159.4	72.7	147.3
200.5	94.2	129.7	260.3	234.3	282.0	138.2	183.5	213.1	172.2
312.0	204.2	171.8	212.2	173.0	202.7	195.3	202.7	244.1	193.5
141.6	63.1	182.6	138.6	391.4	156.7	270.3	220.8	138.8	177.6
228.4	323.7	201.6	161.2	199.4	159.1	238.9	197.8	297.6	243.3
277.0	240.4	173.5	202.1	254.2	240.6	214.7	219.8	259.7	363.8
276.8	204.8	226.3	237.5	271.7	278.4	250.0	357.2	263.1	255.3
123.5	288.3	344.2	300.5	230.0	298.4	235.1	459.9	297.5	345.0
392.8	281.5	401.5	328.6	274.7	436.9	258.0	310.0	190.1	341.1

MEAN 227.8

VARIATE 2

7	8	6	6	7	6	5	6	5	6
6	7	6	7	5	7	8	7	5	5
5	6	7	7	6	8	7	5	6	6
6	6	6	7	7	6	8	7	5	5
4	8	5	9	7	6	6	6	9	7
7	8	8	5	6	7	9	5	9	7
10	7	8	9	7	6	8	6	8	9
7	7	7	8	10	6	6	8	5	7
9	7	8	9	9	8	7	3	6	6

MEAN 7

VARIATE 3

1	1	1	1	2	2	4	2	2	3
2	3	2	4	3	4	5	2	3	3
4	2	5	3	6	3	4	4	2	3
5	2	3	3	5	5	5	3	2	4
4	4	5	5	6	5	5	5	4	3
3	5	6	4	6	4	7	2	6	6
6	4	5	4	6	6	7	6	6	7
6	5	8	4	3	5	4	7	6	8
6	6	7	6	6	7	7	7	5	7

MEAN 4

VARIATE 4

28	37	25	26	30	25	29	32	26	24
31	34	25	25	28	30	23	25	25	27
24	23	27	26	26	23	26	23	27	24
23	33	29	26	31	25	31	33	23	27
24	23	31	25	33	24	25	28	24	24
24	24	24	28	25	24	25	23	26	23
24	23	27	25	23	24	23	24	24	25
25	24	23	24	25	26	23	23	24	23
23	25	25	24	28	22	35	27	27	24

MEAN 26

VARIATE 6

7	6	9	8	10	12	20	15	10	18
15	16	13	21	25	19	22	17	17	13
26	17	20	24	17	27	23	22	16	23
14	8	19	16	28	15	25	26	17	19
18	23	37	12	16	19	29	22	31	30
31	23	29	22	28	25	32	27	30	38
32	20	27	20	23	38	20	34	20	28
15	28	32	27	24	34	21	39	28	28
39	22	32	47	37	41	31	29	38	31

MEAN 23

VARIATE 7

96.1	28.9	161.2	116.7	55.1	64.4	31.2	79.7	36.3	49.1
100.3	31.4	64.9	65.1	78.1	70.5	27.6	91.8	71.0	57.4
78.0	102.1	34.4	70.7	28.8	67.6	48.8	50.7	122.1	64.5
28.3	31.5	60.9	46.2	78.3	31.3	54.1	73.6	69.4	44.4
57.1	80.9	40.3	32.2	33.2	31.8	47.8	39.6	74.4	81.1
92.3	48.1	28.9	50.5	42.4	60.2	30.7	109.9	43.3	60.6
46.1	51.2	45.3	59.4	45.3	46.4	35.7	59.5	43.8	36.5
20.6	57.7	43.0	75.1	76.7	59.7	58.8	65.7	49.6	43.1
65.5	46.9	57.4	54.8	45.8	62.4	36.9	44.3	38.0	48.7

MEAN 57.4

VARIATE 8

13.7	4.8	17.9	14.6	11.0	10.7	6.2	10.6	7.3	8.2
13.4	5.9	10.0	12.4	9.4	14.8	6.3	10.8	12.5	13.2
12.0	12.0	8.6	8.8	10.2	7.5	8.5	9.2	15.3	8.4
10.1	7.9	9.6	8.7	14.0	10.4	10.8	8.5	8.2	9.3
12.7	14.1	5.4	13.4	12.5	8.4	8.2	9.0	9.6	8.1
8.9	10.5	6.0	9.2	9.1	9.6	6.7	8.1	8.7	9.6
8.6	10.2	8.4	11.9	11.8	7.3	12.5	10.5	13.2	9.1
8.2	10.3	10.8	11.1	9.6	8.8	11.2	11.8	10.6	12.3
10.1	12.8	12.5	7.0	7.4	10.7	8.3	10.7	5.0	11.0

MEAN 10.0

TREATMENT E

			MIN	MEAN	MAX
VAR	1	= MOTHER TUBER WEIGHT G	5.40000	55.07000	154.1000
	2	= EYE NO.	3.00000	7.16667	12.0000
	3	= STEM NO.	1.00000	4.10000	10.0000
	4	= DAYS TO EMERGENCE	22.00000	27.94440	39.0000
	5	= TUBER YIELD G/HILL	20.40000	225.99000	481.3000
	6	= TUBER NO./HILL	4.00000	21.12220	42.0000
	7	= TUBER YIELD G/STEM	10.20000	62.40720	203.0000
	8	= MEAN TUBER WEIGHT G	2.84667	11.09180	21.2444

VARIATE 1

5.4	6.4	9.7	10.6	13.5	13.9	16.4	19.6	20.6	21.9
22.0	22.1	22.1	23.5	23.9	24.9	25.7	26.0	26.0	26.1
26.2	27.5	29.0	29.1	29.2	29.3	29.4	31.7	32.4	34.1
35.4	37.1	37.2	37.5	37.6	37.9	39.3	39.3	39.7	41.3
41.8	42.7	43.0	45.0	46.8	47.3	47.4	47.6	48.4	48.5
52.7	58.9	60.3	64.1	64.2	64.3	65.0	65.1	66.8	67.0
67.0	67.3	67.5	68.4	72.5	73.5	74.2	75.6	76.5	79.5
82.0	86.3	92.2	92.3	94.2	94.8	96.2	100.6	101.4	102.8
103.6	105.7	105.9	107.6	109.5	109.8	110.5	113.3	124.1	154.1

MEAN 55.1

VARIATE 5

20.4	57.3	75.8	106.1	134.6	203.0	116.5	122.2	159.5	174.3
167.8	281.6	120.5	98.4	177.0	159.0	149.8	150.3	167.1	258.3
194.1	299.5	179.6	209.8	254.5	324.6	191.2	119.7	238.9	189.4
223.3	42.7	191.0	221.0	156.6	260.8	147.9	210.6	356.4	216.5
78.4	277.7	146.7	130.5	200.2	298.9	214.2	310.5	247.6	275.8
147.5	302.3	218.9	197.0	212.5	224.3	279.0	232.3	217.8	319.5
317.4	260.5	283.5	285.4	329.5	148.7	264.8	223.7	247.6	276.7
331.1	344.3	270.7	279.3	247.7	227.3	296.5	260.3	170.1	277.4
374.8	316.6	447.4	273.2	332.7	303.5	209.3	342.8	481.3	255.8

MEAN 226.0

VARIATE 2

5	6	6	8	6	7	6	8	8	8
6	7	6	7	8	9	4	6	7	9
9	8	6	6	6	6	6	6	7	7
6	6	10	5	6	7	12	11	6	7
5	7	5	8	7	8	6	8	7	7
6	6	8	7	9	6	7	9	8	5
10	10	7	9	10	4	7	7	9	7
8	9	8	8	6	6	6	9	3	11
8	5	9	8	7	8	7	7	7	6

MEAN 7

VARIATE 3

2	2	2	3	2	1	3	2	2	3
3	4	2	1	2	1	1	4	3	4
4	5	3	3	3	3	2	3	5	4
2	4	2	3	2	4	2	5	3	3
4	6	2	5	3	5	4	4	5	5
3	4	5	4	4	6	6	3	3	4
3	5	3	7	5	5	4	5	4	5
9	6	5	10	5	8	3	7	6	7
6	5	7	7	6	6	3	7	8	5

MEAN 4

VARIATE 4

39	34	35	31	35	33	30	34	29	30
31	26	30	34	23	24	28	26	27	30
30	24	24	24	24	26	24	33	26	23
34	36	26	22	30	26	29	26	24	25
25	25	33	37	25	26	23	24	31	26
24	25	26	26	24	30	30	27	30	33
26	28	33	28	30	38	26	25	27	33
24	25	25	23	25	29	26	25	36	26
26	30	26	25	25	24	26	28	25	27

MEAN 28

VARIATE 6

4	8	8	14	7	13	10	6	15	17
27	14	11	8	13	13	10	14	19	19
18	21	17	22	26	24	9	14	26	14
17	15	20	13	12	26	12	16	25	17
9	29	12	23	24	26	29	31	21	32
13	22	22	17	28	27	30	20	20	29
24	27	22	25	32	16	33	24	20	24
42	25	25	24	27	24	23	27	26	26
33	24	41	30	33	30	19	28	39	30

MEAN 21

VARIATE 7

10.2	28.7	37.9	35.4	67.3	203.0	38.8	61.1	79.8	58.1
55.9	70.4	60.3	98.4	88.5	159.0	149.8	37.6	55.7	64.6
48.5	59.9	59.9	69.9	84.8	108.2	95.6	39.9	47.8	47.3
111.6	10.7	95.5	73.7	78.3	65.2	73.9	42.1	118.8	72.2
19.6	46.3	73.4	26.1	66.7	59.8	53.6	77.6	49.5	55.2
49.2	75.6	43.8	49.3	53.1	37.4	46.5	77.4	72.6	79.9
105.8	52.1	94.5	40.8	65.9	29.7	66.2	44.7	61.9	55.3
36.8	57.4	54.1	27.9	49.5	28.4	98.8	37.2	28.4	39.6
62.5	63.3	63.9	39.0	55.5	50.6	69.8	49.0	60.2	51.2

MEAN 62.4

VARIATE 8

5.1	7.2	9.5	7.6	19.2	15.6	11.6	20.4	10.6	10.3
6.2	20.1	11.0	12.3	13.6	12.2	15.0	10.7	8.8	13.6
10.8	14.3	10.6	9.5	9.8	13.5	21.2	8.5	9.2	13.5
13.1	2.8	9.5	17.0	13.1	10.0	12.3	13.2	14.3	12.7
8.7	9.6	12.2	5.7	8.3	11.5	7.4	10.0	11.8	8.6
11.3	13.7	9.9	11.6	7.6	8.3	9.3	11.6	10.9	11.0
13.2	9.6	12.9	11.4	10.3	9.3	8.0	9.3	12.4	11.5
7.9	13.8	10.8	11.6	9.2	9.5	12.9	9.6	6.5	10.7
11.4	13.2	10.9	9.1	10.1	10.1	11.0	12.2	12.3	8.5

MEAN 11.1

APPENDIX 5

Sprout Growth in Store

1967 Seed crop, var "Craigs Alliance"

i) % tubers with visible sprouts -

a) Complete samples

Days after harvest	Treatment NPK No.	NPK %	NP No.	NP %	K No.	K %	Nil No.	Nil %
96	0	0	1	0.6	5	3.2	0	0
108	3	1.7	3	1.8	5	3.2	1	0.7
115	26	14.6	8	4.8	11	7.1	4	2.7
123	61	34.3	22	13.3	46	29.9	18	12.3
132	142	79.8	74	44.6	111	72.1	87	59.6
147	165	92.7	119	71.7	134	87.0	115	78.8
189	177	99.4	156	94.0	148	98.7	143	97.3
Tuber No.	178		166		150		147	

b) Small matched tubers

96	1	2.5	0	0	3	7.5	0	0
108	2	5.0	1	2.5	4	10.0	0	0
115	9	22.5	1	2.5	4	10.0	1	2.5
123	18	45.0	2	5.0	6	15.0	5	7.5
132	30	75.0	12	30.0	25	57.5	19	47.5
147	35	87.5	28	70.0	32	77.5	30	75.0
189	39	97.5	38	95.0	40	100.0	39	97.5
Tuber No.	40		40		40		40	

ii) % eyes with visible sprouts -

a) Complete samples

Days after harvest	Treatment NPK No.	NPK %	NP No.	NP %	K No.	K %	Nil No.	Nil %
96	4	0.3	0	0	17	1.4	0	0
108	8	0.6	13	0.9	17	1.4	3	0.3
115	71	5.3	27	1.8	20	1.7	8	0.7
123	157	11.8	62	4.2	107	8.9	22	2.0
132	497	37.2	190	13.0	319	26.5	83	7.4
147	596	44.6	423	28.9	421	35.0	339	30.3
189	553	41.4	631	43.0	671	55.7	528	47.1
Eye No.	1335		1466		1204		1120	

b) Small matched tubers

96	1	0.4	0	0	9	3.5	0	0
108	5	2.0	1	0.3	13	5.0	0	0
115	29	11.9	1	0.3	13	5.0	4	1.4
123	51	20.9	5	1.8	15	5.8	9	3.1
132	86	35.2	25	9.0	57	22.0	46	15.8
147	95	38.9	75	26.9	78	30.1	75	25.8
189	116	47.5	115	41.2	126	48.6	132	45.4
Eye No.	244		279		259		291	

iii) Sprout growth on matched tubers

a) Tuber weight (g)				b) Eye no. per tuber				c) Sprout no. per tuber				
NPK	NP	K	Nil	NPK	NP	K	Nil	NPK	NP	K	Nil	
2.4	2.4	2.6	2.3	4	4	4	4	1	1	2	1	
3.5	3.4	3.7	3.2	4	5	5	4	2	0	2	1	
4.0	4.0	4.2	4.3	5	6	4	7	2	1	1	3	
5.2	5.2	5.2	5.3	4	6	5	4	1	2	2	1	
6.1	6.4	5.5	6.1	5	4	5	5	3	2	2	2	
8.2	8.1	7.6	8.2	6	6	5	5	0	2	3	5	
9.0	9.2	9.1	9.8	5	7	5	6	3	2	3	1	
10.4	10.4	10.8	10.7	4	3	6	5	2	0	3	2	
12.3	12.8	12.7	12.4	6	6	4	5	3	3	3	2	
13.1	13.4	13.2	13.3	9	6	5	5	1	2	3	0	
14.3	14.3	14.3	13.7	6	5	5	6	3	2	2	1	
15.5	15.6	15.5	15.4	5	5	5	7	3	3	3	2	
16.8	16.6	16.0	16.9	6	7	7	7	3	2	4	3	
19.0	18.9	19.1	19.1	4	5	6	6	1	1	5	3	
20.2	20.2	20.0	20.2	6	8	7	6	3	4	1	3	
22.3	22.7	22.4	22.1	6	6	6	6	3	4	2	2	
23.4	23.4	23.4	23.0	7	6	6	8	3	1	1	3	
24.1	24.0	24.1	23.1	6	5	6	11	2	1	2	3	
24.3	24.7	24.4	25.1	5	8	7	7	2	3	2	3	
25.5	25.4	25.7	25.3	7	8	6	7	3	5	3	4	
Σ 279.6	281.1	279.5	279.5	110	116	109	121	44	41	49	45	Σ
M 14.0	14.0	14.0	14.0	5.5	5.8	5.5	6.1	2.2	2.0	2.5	2.3	M

d) Largest sprout weight (mg)

	NPK	NP	K	Nil
	9	1	19	2
	3	0	2	24
	3	1	1	6
	51	2	9	11
	42	10	10	8
	0	5	42	17
	42	32	30	4
	122	0	12	70
	12	6	16	91
	216	9	4	0
	46	36	44	60
	60	11	34	35
	122	52	12	13
	4	4	40	93
	108	53	38	46
	174	111	239	93
	83	1	9	39
	118	6	300	101
	77	112	60	43
	90	29	128	18
Σ	1382	481	1049	774
M	69.1	24.0	52.5	38.7

e) Total sprout weight per tuber (mg)

NPK	NP	K	Nil	
9	1	32	2	
6	0	3	24	
5	1	1	14	
51	3	14	11	
86	13	16	9	
0	10	56	28	
84	35	61	4	
124	0	18	91	
27	7	32	103	
216	14	12	0	
89	53	49	60	
108	22	49	47	
146	73	31	35	
4	4	108	142	
188	139	38	118	
231	251	369	96	
202	1	9	96	
219	6	429	141	
89	181	83	87	
134	209	231	66	
2018	1023	1641	1174	Σ
100.9	51.2	82.0	58.7	M

a) Tuber weight (g)

	NPK	NP	K	Nil
	28.6	28.5	28.0	28.5
	32.0	31.8	32.2	32.0
	32.3	32.9	33.1	32.3
	33.6	33.0	33.4	33.5
	36.9	36.5	36.8	36.9
	38.8	38.2	36.9	38.1
	41.1	40.6	41.6	41.0
	41.9	41.3	42.0	41.8
	42.6	43.0	42.5	43.2
	46.3	46.3	46.5	46.4
	46.6	46.7	46.8	46.8
	47.5	47.4	47.7	47.2
	48.0	48.7	47.9	48.6
	50.8	50.8	50.5	50.6
	51.5	51.2	51.8	54.0
	52.6	52.6	52.9	54.1
	54.5	54.9	54.3	54.9
	55.3	55.8	57.3	55.9
	56.1	56.5	57.9	56.6
	58.1	58.3	58.2	58.1
Σ	895.1	895.0	898.3	900.5
M	44.8	44.8	45.0	45.0

b) Eye no. per tuber

NPK	NP	K	Nil
5	8	7	7
8	7	7	7
6	6	7	6
6	8	5	5
8	9	8	10
7	7	10	11
6	8	6	9
5	11	8	9
7	8	8	9
7	11	7	8
8	6	8	8
6	9	5	10
5	9	6	8
8	8	10	9
6	8	8	11
7	9	8	7
7	8	9	10
8	8	8	8
7	8	7	9
7	7	8	8
134	163	150	169
6.7	8.2	7.5	8.5

c) Sprout no. per tuber

NPK	NP	K	Nil	
2	3	7	2	
5	1	7	4	
5	5	7	4	
2	5	5	2	
4	2	8	7	
4	4	10	3	
4	5	6	5	
2	3	8	2	
5	2	8	4	
4	2	7	4	
6	4	8	4	
3	3	5	7	
2	7	6	5	
3	6	10	2	
4	5	8	8	
5	7	8	5	
3	5	9	6	
3	2	8	5	
3	4	7	4	
3	2	8	4	
72	77	150	87	Σ
3.6	3.8	7.5	4.4	M

d) Largest sprout weight (mg)

NPK	NP	K	Nil
16	53	261	31
90	213	45	121
145	2	113	63
141	21	76	14
218	332	40	123
165	90	25	85
170	124	116	31
71	118	166	321
23	37	72	186
126	206	22	59
256	83	156	299
70	116	113	40
257	121	65	134
367	51	113	301
311	338	346	33
156	271	106	207
89	125	82	130
184	73	536	113
452	290	260	157
207	29	46	120
Σ 3514	2693	2759	2568
M 175.7	134.7	138.0	128.4

e) Total sprout weight per tuber (mg)

NPK	NP	K	Nil	
32	64	396	81	
217	213	45	148	
375	10	155	247	
235	74	89	16	
277	432	116	176	
376	197	74	202	
330	234	161	63	
91	343	177	421	
46	45	205	242	
254	268	57	137	
722	292	220	453	
117	181	392	176	
496	303	225	213	
722	156	183	343	
563	512	783	116	
341	411	288	463	
97	293	93	202	
351	80	864	573	
604	428	391	316	
474	55	140	250	
6720	4591	5054	4838	Σ
336.0	229.6	252.7	241.9	M

a) Tuber weight (g)

	NPK	NP	K	Nil
	58.1	58.3	58.2	58.1
	58.8	58.7	58.5	59.8
	59.8	60.0	59.8	60.2
	61.4	61.0	61.1	61.8
	64.8	64.7	64.0	64.7
	65.2	65.3	65.1	66.0
	67.5	67.3	67.7	66.6
	70.7	70.8	70.5	67.4
	71.8	72.0	70.5	69.6
	73.3	72.8	74.1	72.4
	77.0	77.0	77.3	
	81.4	81.5	81.0	
	82.6	82.7	83.4	
	84.5	84.8	84.3	
	87.0	86.5	86.1	
	88.3	88.0	88.1	
	89.8	89.5	89.9	
	92.0	92.3	92.4	
	98.5	97.0	98.4	
	101.3	101.8	101.1	
Σ	1533.8	1532.0	1532.1	646.6
M	76.7	76.6	76.6	64.7

b) Eye no. per tuber

NPK	NP	K	Nil
7	7	8	8
8	9	9	12
7	8	9	8
8	6	7	9
7	7	8	10
8	7	8	10
8	8	9	9
7	8	9	12
8	10	7	8
5	6	9	8
7	9	7	
8	9	8	
7	6	8	
6	10	10	
8	9	7	
6	10	6	
7	10	9	
9	10	10	
6	10	6	
8	11	9	
145	170	163	94
7.3	8.5	8.2	9.4

c) Sprout no. per tuber

NPK	NP	K	Nil	
3	2	6	4	
3	7	5	6	
2	5	7	5	
4	3	4	8	
3	4	7	4	
5	7	6	6	
5	4	6	4	
4	5	6	8	
7	8	4	6	
3	5	8	4	
4	5	5		
3	8	8		
2	4	5		
2	5	7		
6	6	5		
4	6	3		
5	7	6		
5	8	5		
5	3	8		
7	6	5		
82	108	116	55	Σ
4.1	5.4	5.8	5.5	M

d) Largest sprout weight (mg)

NPK	NP	K	Nil
207	29	46	120
403	42	127	118
417	83	73	59
167	92	234	82
176	140	33	83
47	124	76	61
117	170	125	103
83	165	30	31
161	63	123	159
129	231	35	67
91	593	138	
51	57	67	
34	102	144	
28	112	188	
177	179	399	
149	115	121	
50	253	232	
65	153	172	
243	72	220	
605	160	196	
Σ 3400	2935	2779	883
M 170.0	146.8	139.0	88.3

e) Total sprout weight per tuber (mg)

NPK	NP	K	Nil	
474	55	140	250	
807	154	319	237	
502	168	205	181	
403	207	500	388	
252	297	141	285	
160	206	297	385	
400	276	221	239	
120	755	121	121	
614	247	219	494	
225	501	99	105	
279	889	342		
132	316	185		
37	273	274		
39	249	327		
581	748	984		
232	276	203		
123	884	60		
157	813	636		
685	167	699		
1190	390	398		
7412	7871	6370	2685	Σ
370.8	393.6	318.5	268.5	M

a) Tuber weight (g)

	NPK	NP	K	Nil
	102.7	102.1	102.9	
	112.0	111.0	115.0	
	118.8	119.8	118.4	
	120.8	120.8	120.2	
	123.3	122.8	123.2	
	126.3	126.9	128.6	
	130.1	131.0		
	133.3	132.5		
	136.3	137.1		
	145.0	146.6		
	154.0	155.6		
	157.8	158.3		
	163.5	162.1		
	164.5	164.2		
	171.7	171.7		
	178.7	179.1		
	178.8	179.8		
	206.4	202.4		
	212.8	213.4		
	219.5	219.8		
Σ	3055.7	3055.0		
M	152.8	152.8		

b) Eye no. per tuber

NPK	NP	K	Nil
6	10	8	
9	10	11	
8	8	11	
9	11	11	
7	13	9	
7	10	9	
8	10		
8	12		
9	8		
8	10		
8	11		
8	14		
9	10		
10	11		
9	8		
10	12		
10	10		
9	11		
8	13		
9	14		
169	216		
8.5	10.8		

c) Sprout no. per tuber

NPK	NP	K	Nil	
3	7	6		
6	7	9		
5	8	7		
8	5	9		
4	5	3		
5	6	7		
5	7			
4	6			
5	3			
6	5			
7	8			
4	10			
7	8			
6	7			
9	4			
8	8			
4	7			
7	10			
6	9			
6	9			
115	139			Σ
5.8	7.0			M

d) Largest sprout weight (mg)

NPK	NP	K	Nil
29	95	224	
180	364	212	
148	541	208	
224	240	286	
170	124	135	
322	150	186	
126	228		
167	239		
223	93		
283	142		
50	126		
115	527		
359	220		
123	218		
305	137		
137	240		
152	174		
87	102		
174	466		
312	204		
Σ 3686	4630		
M 138.3	231.5		

e) Total sprout weight per tuber (mg)

NPK	NP	K	Nil
62	369	498	
301	879	565	
360	970	398	
725	900	933	
211	651	279	
720	489	388	
260	771		
326	492		
534	181		
872	489		
167	346		
234	1289		
1001	477		
227	950		
1227	319		
491	582		
316	379		
310	602		
515	1589		
868	898		
9727	13622		
486.4	681.1		